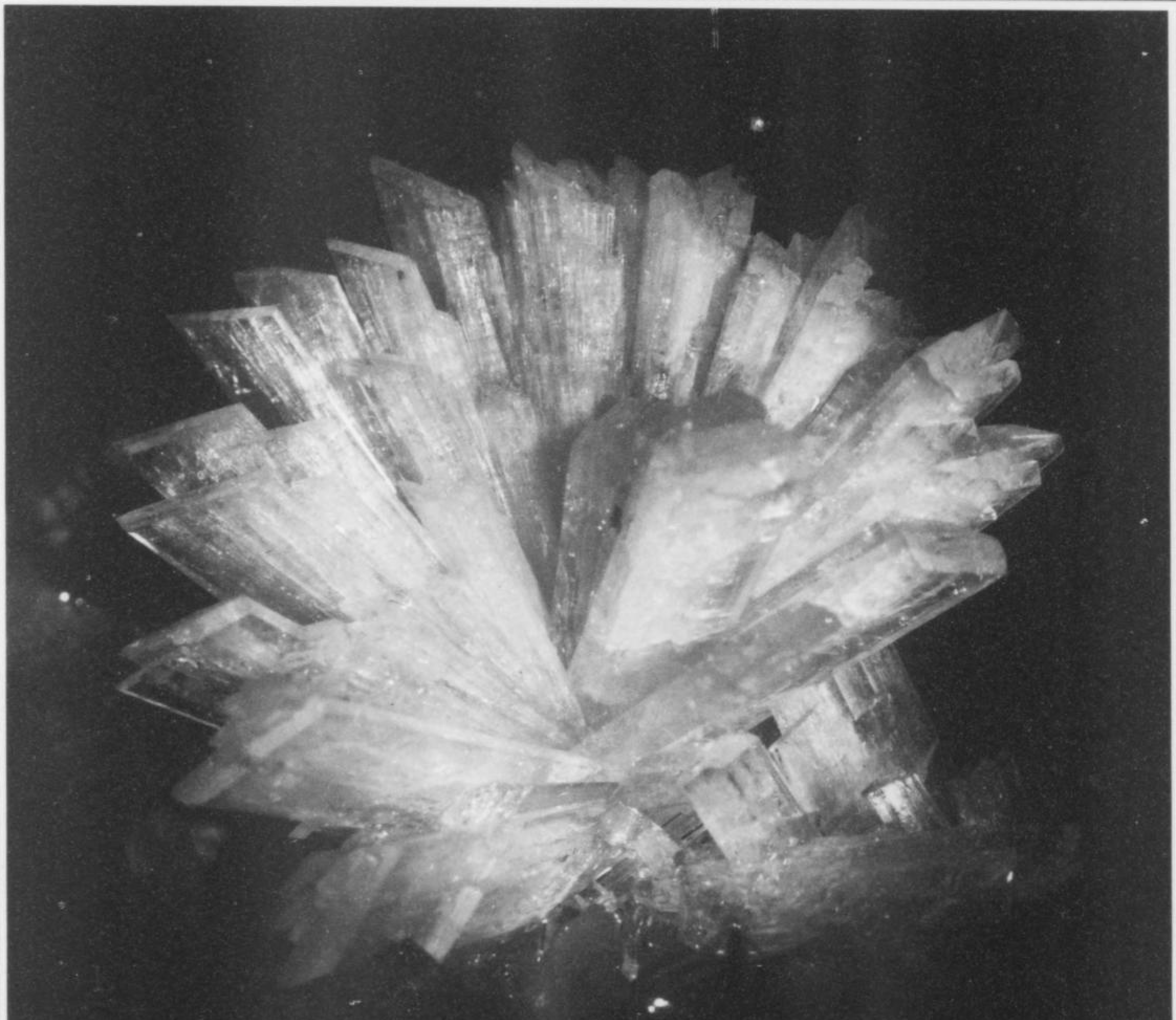
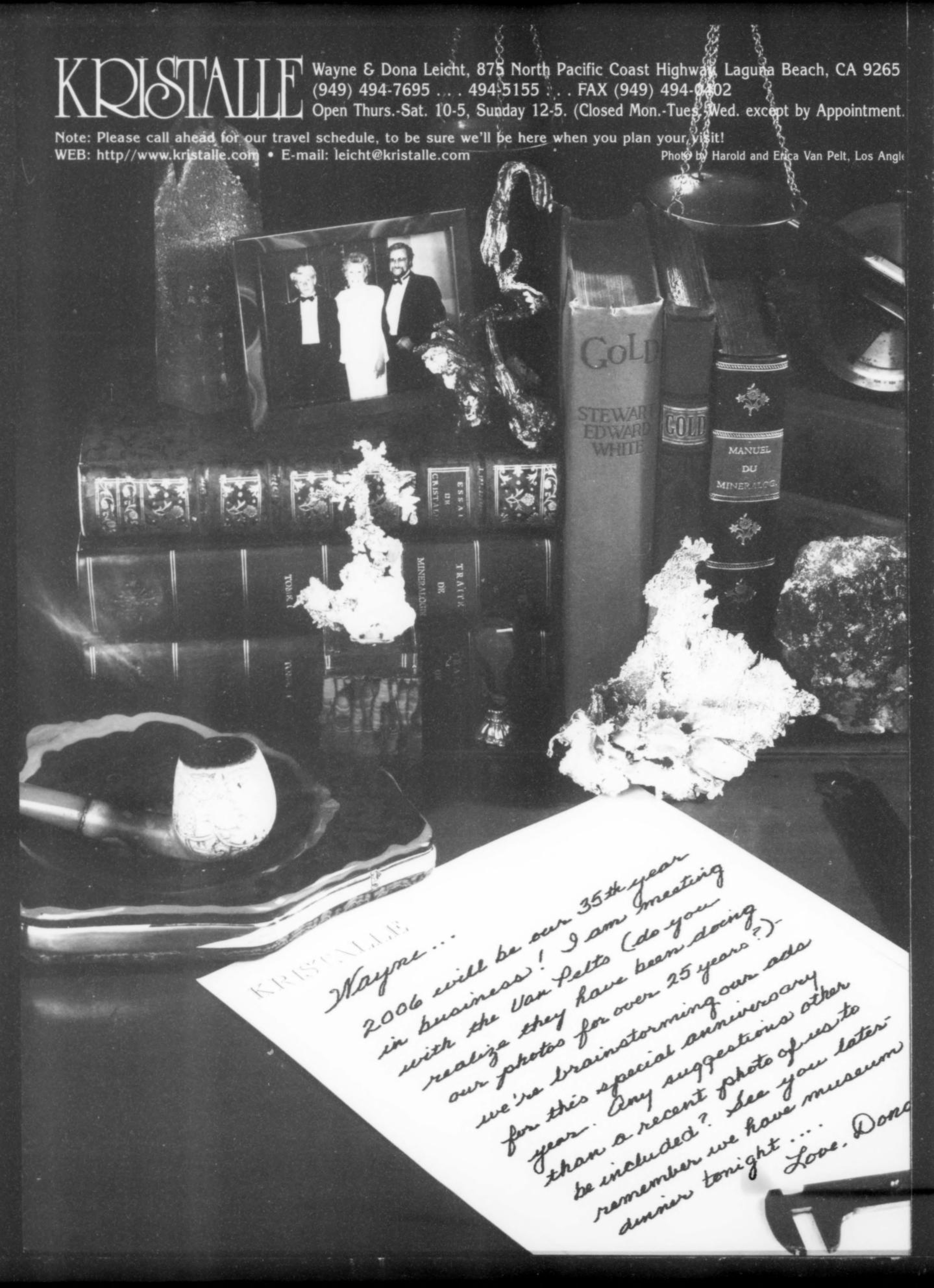
Llallagua



Mineralogical Record

March-April 2006 ❖ Volume 37 Number 2 ❖ $15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TRAITÉ DE MINERALOGIE
KRISTALLE
Wayne...
2006 will be our 35th year in business! I am meeting with the Van Pelts (do you realize they have been doing our photos for over 25 years?)- we're brainstorming our ads for this special anniversary year. Any suggestions other than a recent photo of us to be included? See you later- remember we have museum dinner tonight...
Love, Dona

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*Continued on p. 192

THE MINERALOGICAL RECORD

March–April 2006 Volume Thirty-seven, Number Two

Articles

Columns

COVER: PARAVAUXITE crystal spray, perhaps the finest known, 2 cm, from Llallagua, Bolivia. Mark Chance Bandy collection; current owner unknown, presumably still in the possession of the Bandy family. Photo by Wolfgang Mueller.

The Mineralogical Record
(ISSN 0026-4628) is published bi-monthly for $58 per year (U.S.) by Mineralogical Record, Inc., a non-profit organization, 7413 N. Mowry Place, Tucson, AZ 85741. Periodicals postage paid at Tucson, Arizona and additional mailing offices. POSTMASTER: Send address changes to: The Mineralogical Record, P.O. Box 35565, Tucson, AZ 85740.

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notes from the EDITORS

New York mineral dealer Roy Hopping (1872–ca.1907)

Label Archive

Our article on the Mineralogical Record Label Archive drew more response than any article published in the last 20 years, and we would like to thank everyone who wrote to express support or offer help. Posting it all will be a huge job that will take several years to finish, but we now have volunteers and connections in Germany, France and England to assist in the historical background research, so the results should ultimately be quite fascinating as we develop a slowly growing overall picture of mineral dealing and collecting worldwide over the last 200 years or so. I have decided that we will also occasionally post biographical background (where available) for collectors or dealers for whom we do not yet have a label—in hopes that a relevant one will turn up in the future, and we can at least obtain a scan of it. This will also remove an arbitrary bias (i.e. whether we happen to have a label or not) from the historical coverage. For the most part, however, we will work from our enormous label collection, now numbering over 13,000 examples, thanks to the recent acquisition of two major European collections.

We will also not be restricting ourselves merely to the labels for illustrations, but will be including portraits, where available, and even interesting old ads for certain dealers. Though this will be even more work on our part, it will, I think, add to the fun and will present a more fully rounded historical view.

During the past summer, when we had more time for such projects than during our busy season between the the Denver and Tucson Shows, I was able to post all of the A's and B's and part of the C's on our website, with occasional digressions forward in the

THE MINERAL COLLECTOR. iii

Franklin Furnace.

Hardystonite from Franklin Furnace, N. J., the new mineral described by Dr. Wolff, fine cleavable pieces with black franklinite *cheap*, 2x2 to 3x4 inches, 15c, 20c, 25c, 50c, 75c.

Bementite, the best specimens ever obtained *also very cheap*. A rare, interesting, hydrous manganese silicate, named after Mr. Clarence S. Bement, whose fine collection is now in the American Museum. 1½x 1½ to 3x3 inches, 10c. to 50c.

Zincite, now very scarce, good solid red oxide in white calcite, 25c, 35c.

Willemite, finest color, rich yellow green to pellucid brown, 25c, 35c, 50c.

Fowlerite, very bright rose-red rhodonite, large specimens, 20c, 25c, 35c. A very few crystallized groups at 75c. to $1.00.

Other New Arrivals.

Hexagonite, Edwards, N.Y., fine rich purple, crystallized, 10c. to 35c.

Aegirite, Magnet Cove, Ark., large black crystals in white rock, 10c. to 75c. A few specimens with the very rare terminated crystals.

Blue Celestite, Germany, beautiful groups of crystals, 2x2 to 2½x3 inches, 15c. to 75c.

Calcites, Joplin, Mo., beautiful yellow crystals in fine groups, at *very cheap prices*, 10c. to 75c.

ROY HOPPING, 129 FOURTH AVE., NEAR 13TH ST., New York, N. Y.

The American Mineral Cabinet

Is a highly polished oak case with panelled sides, moulded top, carved wooden handles on the drawers and brass label holders which will allow the labels to be removed when soiled.

The drawer-stops are beneath the drawers, which will be appreciated by collectors who have had fine groups crushed by stop blocks. Between the fifth and sixth drawer is a sliding shelf to rest a drawer upon when out of the case for inspection.

Dimension of cabinet: 5 ft. high, 2 ft. square.

Dimensions of drawers:

11 are 18x20x2½ inches inside.
1 is 18x20x4½ inches inside.
1 is 18x20x6½ inches inside.

Capacity: 390 pasteboard trays 3x4 inches, 780 trays 2x3 inches, or 1560 trays 1½x2 inches.

Weight 150 lbs. packed in excelsior and burlap, ready for shipment, price $20.00.

Roy Hopping, 129 FOURTH AVE., NEAR 13th STREET, New York.

Roy Hopping ad from The Mineral Collector, March 1902.

alphabet. Recent work has focused more on the digressions, in order to add in some of the more interesting or prominent entries that readers are likely to want to consult. The problem for readers, of course, is identifying the newly added ones amid the drop-down menu that already lists nearly 500 entries. Here are a few of the more interesting recent additions:

Caswell, John H.
Chamberlain, Steven C.
Chester, Albert H.
Deyrolle, Emile
Eger, Leopold
Egger, Samuel
English, George L.
Fiss, George Washington
Foote, A.E.
Ford, Hugh A.
Fuller, Arthur N.
Newcomet, William S.
Niven, William
Oldach, Frederick J.M.
Otto, Anton
Pennypacker, Charles H.
Perry, Nathaniel H.
Petereit, Albert H.
Pisani, Felix
Rakestraw, George G.
Ralston, J. Grier
Richards, G.H.

Genth, Frederick A.
Gisler, Julius
Grenzig, John A.
Groom-Napier, Charles Ottley
Hedge, Campbell T.
Hopping, Roy
Howell, Edwin E.
Jäger Company, Albin
Jefferis, William W.
Joseph, Joseph
Karabacek, Hans J.
Kendall, Theodore A.
Kirk, Isaac S.
Kline, John W.
Krantz, A. and F.
Kuntze, Otto
Kunz, George F.
Kusche, Arthur E.
Lee, John W.
Lenoir, G.A.
Maucher, Wilhelm
Rothschild, Jules
Russell, Thomas D.
Seeland, Ferdinand
Seymour, Ebenezer
Smith, J. Alden
Spang, Charges & Norman
Stadtmüller, Frank H.
Stadtmüller, Louis
Stilwell, Lucien W.
Stockbridge, Henry
Trainer, John N.
Twidale, Mowbray
Underhill, E.B.
Utman, John C.
Vaux, George
Vaux, William S.
Ward, Henry A.
Williams, Scott J.
Wilson, Newman L.
Winthrop Mineral Shop
Woodend, Daniel C.

I will also let you in on a little secret about the website that may make the Label Archive easier to browse. The Googlebot that indexes our website for Google was unable to get through the drop-down menus, so we created a four-page site-map section just to assist Google, listing every page on the website without using any drop-down menus. You can find this hidden site map by clicking on the crossed hammers symbol at the lower right on our home page. Page two of the site map lists the Label Archive entries posted so far, in two columns, a format which you may find easier to study. Clicking on any entry in the list takes you to that page, just as the drop-down menu would. (The entire Label Archive inventory is posted in the *Axis* section of our website.)

Early Journals

We have been fortunate to acquire for research purposes an extremely rare complete set of *The Exchangers' Monthly* (1885–1890) and partial sets of *Mineralogists' Monthly* (1890-1893) and *Minerals* (1892–1893), the three early American journals by Arthur Chamberlain and William M. Goldthwaite which (along with *The Mineral Collector,* 1896–1909) preceeded the creation of *The American Mineralogist* in 1916. You can read about the history of these early journals in the article "Arthur Chamberlain and his magazines," published in vol.1, no.1, of *The American Mineralogist* (July 1916), and now available online at the Mineralogical Society of America's website: http://www.minsocam.org/msa/collectors_corner/arc/his1.htm

We also have partial runs of other extremely rare early journals including *The Young Mineralogist and Antiquarian* (1884–1885), A.E. Foote's *The Naturalist's Leisure Hour* (1880–1892), *Geologists' Gazette* (1887–1888), Roy Hopping's *American Minerals* (1903), *Maine Minerals* (1934–1935), and complete runs of Henry Dake's *The Mineralogist* (1933– 1964) and *Rocks & Minerals* (1926-present), among others. The study of these early collector magazines, most particularly the advertisements, has been of great help in our historical research on early American mineral dealers and collectors for the Label Archive.

The late Jay Lininger reprinted the complete run of *The Mineral Collector* some years ago, performing a tremendous service for the mineralogical community by preserving a very nearly lost part of the history of mineral collecting, inasmuch as nearly all original

THE EXCHANGERS' MONTHLY

VOL. I. JERSEY CITY, N. J., NOVEMBER, 1885. NO. 1.

FACTS CONCERNING OPALS.

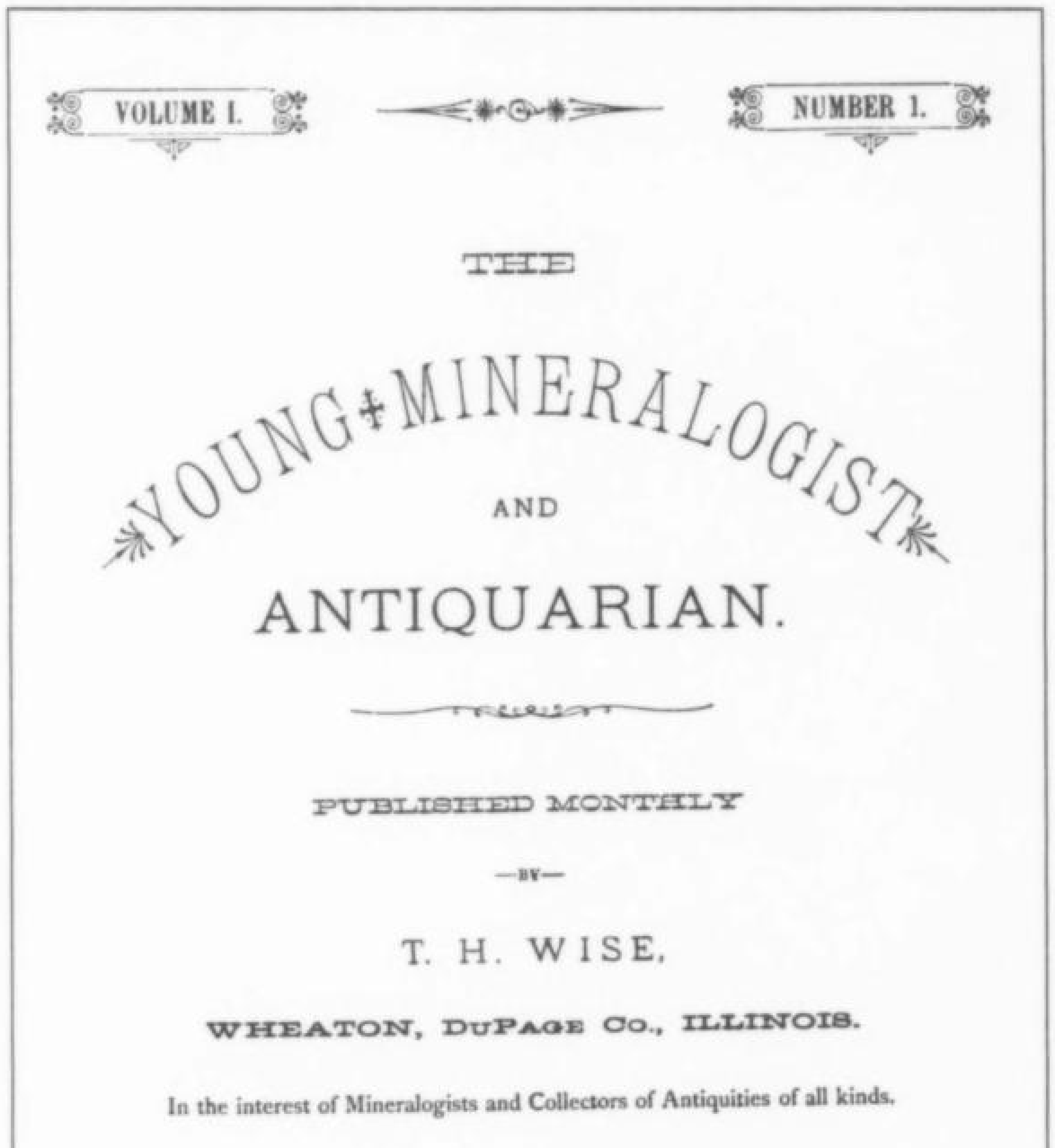
The mineralogists and geologists have offered many clever theories to account for the splendor of the opal, but no one has completely satisfied everybody, and perhaps never will. It is conjectured that it is due either to the presence of water in its composition or to the disintegration of the laminæ or layers of the stone, but even this is not certainly known. The Turks believe that the gem is of celestial origin, and thus escape all difficulties at once. The ancient opal mines have never been discovered, but there were no doubt deposits of the precious stones in Arabia, Syria and perhaps other parts of Asia, from which the ancients obtained their gems.

Central America and Mexico abound in opal bearing districts, which are much more abundant than might be supposed; but perhaps the finest opals of the present day are obtained in Hungary. The fire opal is found in the greatest perfection in the porphyrite rocks near Zimapan, in Mexico; but while this variety is the most beautiful of all opals, it is also the most sensitive, and is frequently ruined beyond hope of repair by damp or exposure, or even by a sudden change in the weather. There is probably no gem, however, which is more subject to injury than the opal. Exposure to the light injures it very materially, though there is not one thing strange about this, the fact being true also of amethyst, the garnet, and almost all other precious colored stones.

As stated, the finest opals are now found in Hungarian mines. When first extracted from their native matrix, the gems are soft, friable, tender and easily broken. The first thing to be done is to expose them to the air and light for a few days, until they have become hard, and then their colors begin to appear. At the same time the change takes place in the gem, it becomes also reduced in size from the evaporation of the quarry water contained in its veins. Great care must be exercised in drying the stone, or it will split and crack in a thousand directions, and become utterly worthless. It is also liable to another calamity, if exposed to a high temperature—that is, of losing iridescence, and, when this once happens, the stone is absolutely worthless.

HOW FISH ARE SPREAD.

In looking over the most recent faunal lists of this portion of the country, writes Dr. C. C. Abbott in his forthcoming "Rambles About Home," I find that much of our zoological literature is somewhat amusing. By a preconceived notion of what should be the geographical distribution of the fishes, and other animals as well, these "systematic" writers gravely assert that in such



VOLUME I. NUMBER 1.

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YOUNG MINERALOGIST

AND

ANTIQUARIAN.

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—BY—

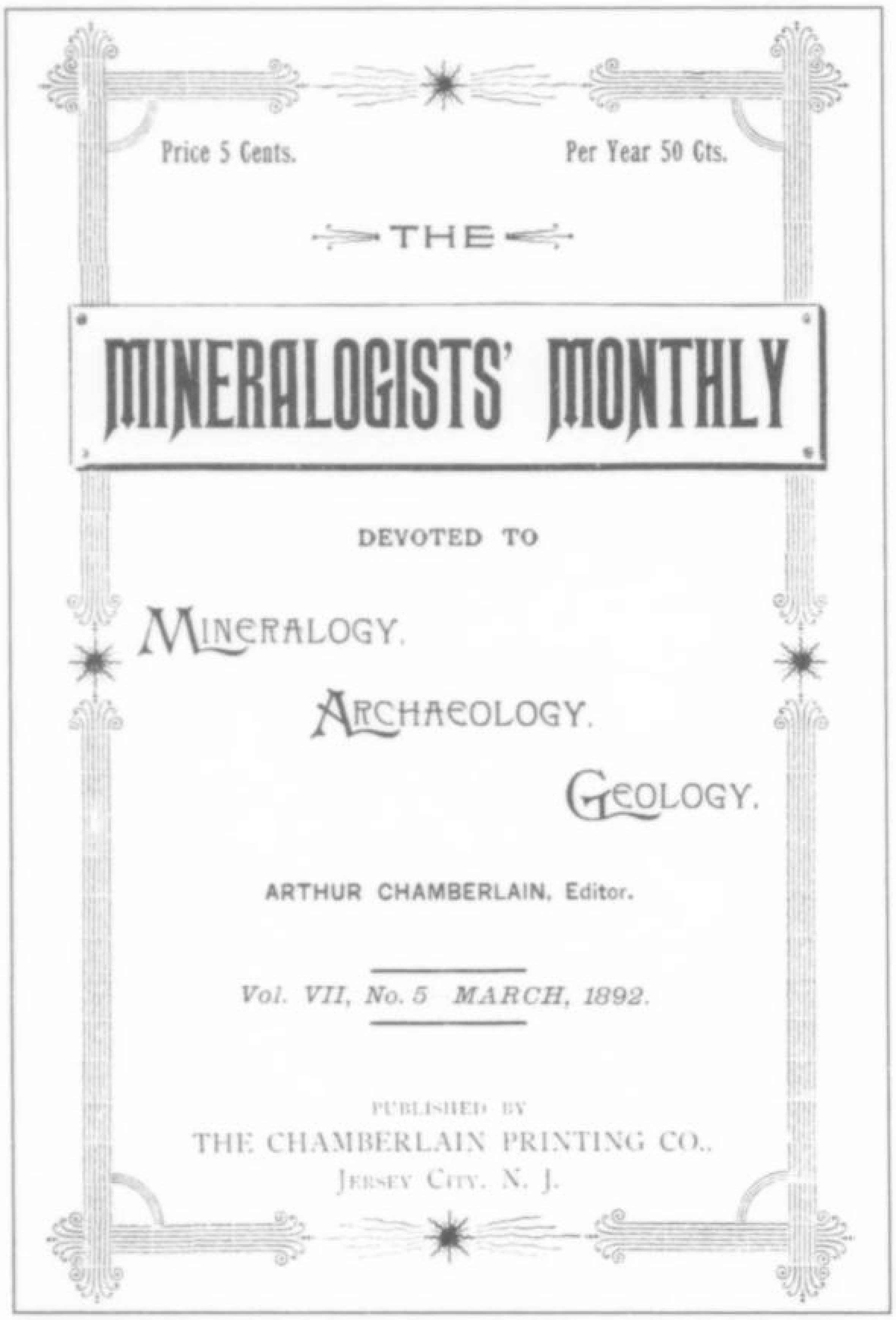
T. H. WISE,

WHEATON, DUPAGE CO., ILLINOIS.

In the interest of Mineralogists and Collectors of Antiquities of all kinds.

75 cents per year in Advance.

WHEATON.
ILLINOIAN PUBLISHING HOUSE
1884.



Price 5 Cents. Per Year 50 Cts.

THE

MINERALOGISTS' MONTHLY

DEVOTED TO

MINERALOGY,

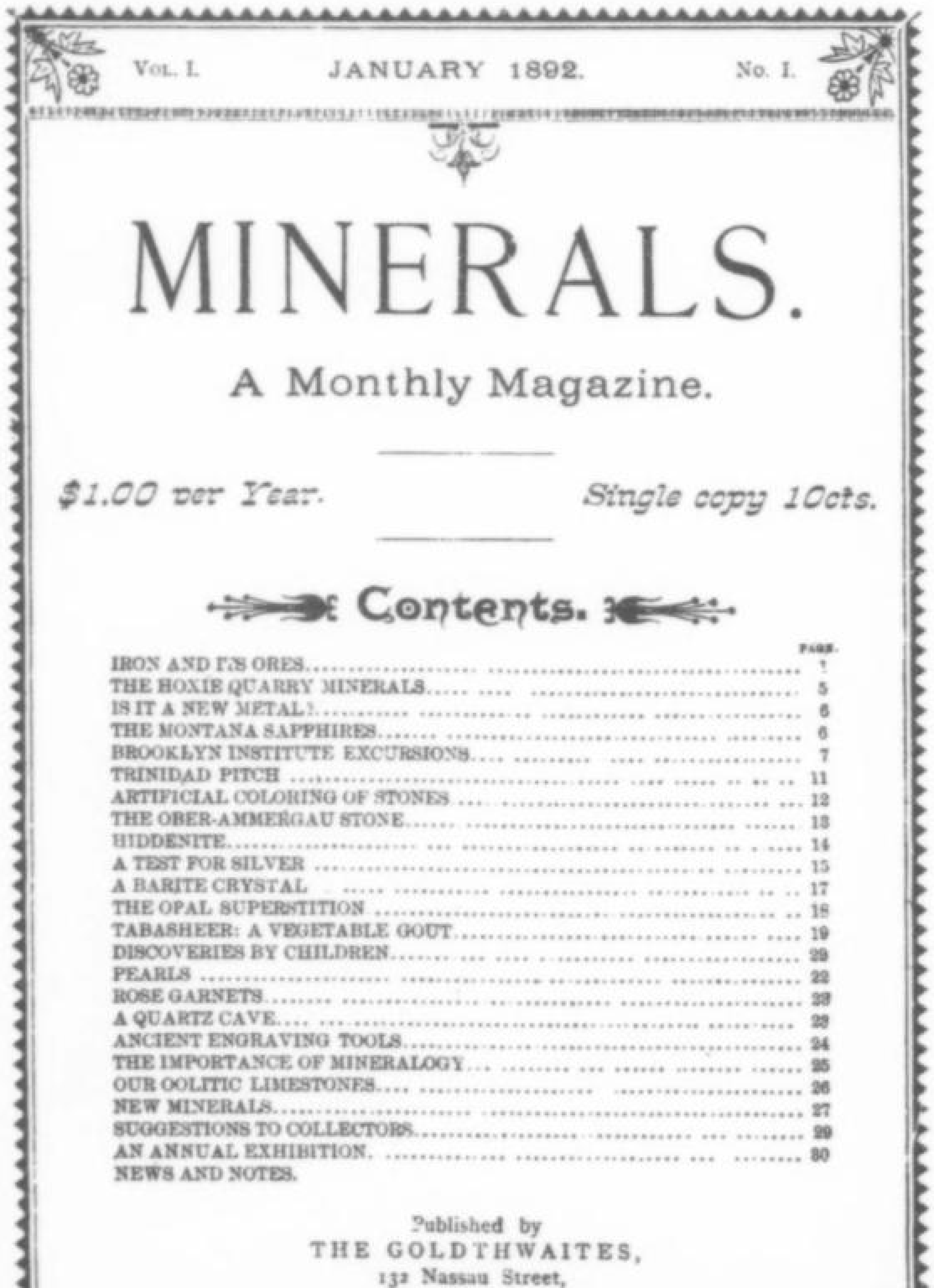
ARCHAEOLOGY,

GEOLOGY.

ARTHUR CHAMBERLAIN, Editor.

Vol. VII, No. 5 MARCH, 1892.

PUBLISHED BY
THE CHAMBERLAIN PRINTING CO.,
JERSEY CITY, N. J.



VOL. I. JANUARY 1892. NO. I.

MINERALS.

A Monthly Magazine.

$1.00 per Year. *Single copy 10cts.*

Contents.

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THE GOLDTHWAITES,
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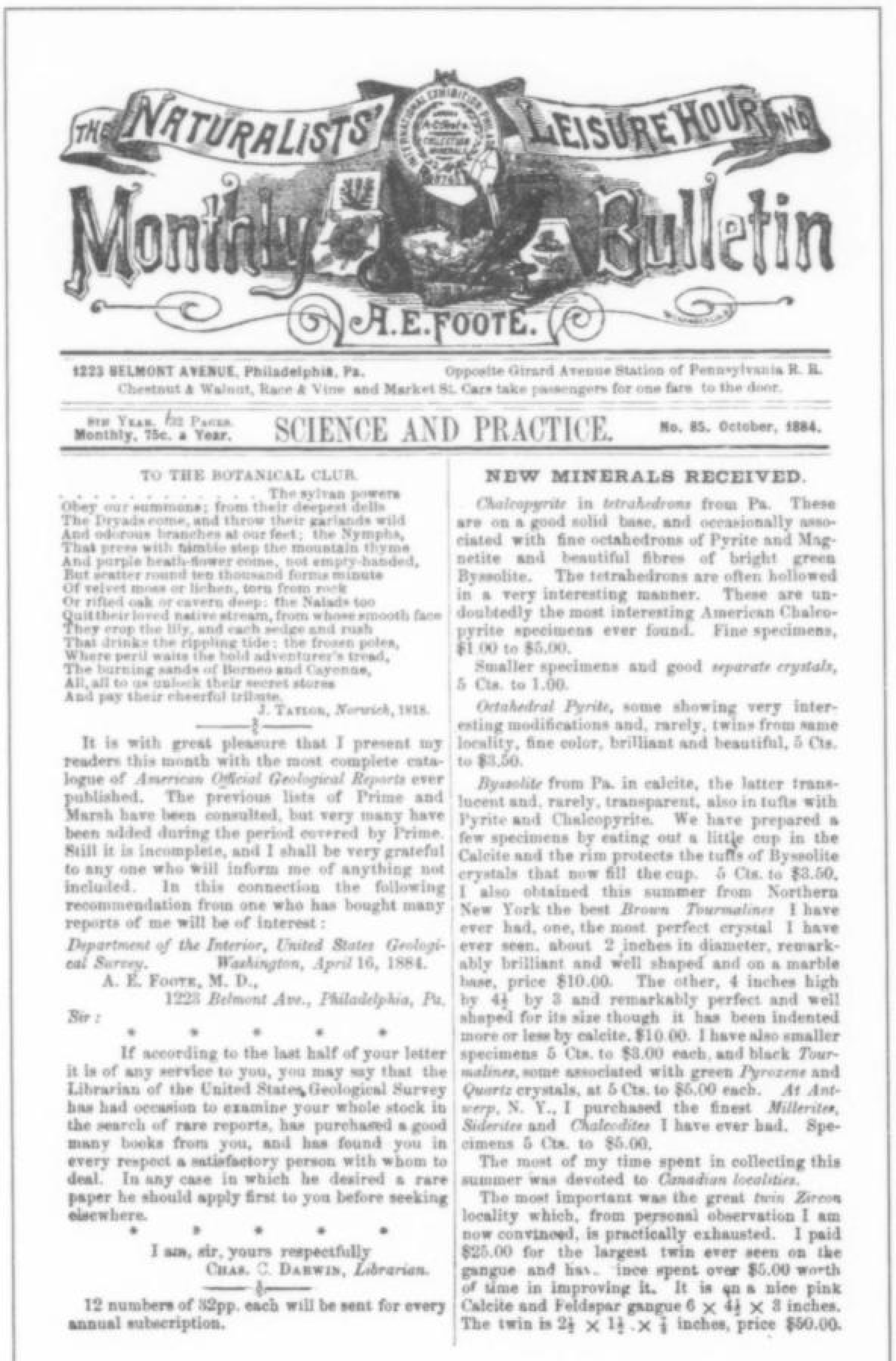
NEW YORK.



THE NATURALISTS' LEISURE HOUR AND MONTHLY BULLETIN

A. E. FOOTE.

1223 BELMONT AVENUE, Philadelphia, Pa. Opposite Girard Avenue Station of Pennsylvania R. R.
Chestnut & Walnut, Race & Vine and Market St. Cars take passengers for one fare to the door.

8TH YEAR. 32 PAGES. Monthly, 75c. a Year. SCIENCE AND PRACTICE. No. 85. October, 1884.

TO THE BOTANICAL CLUB.

. . . . The sylvan powers
Obey our summons; from their deepest dells
The Dryads come, and throw their garlands wild
And odorous branches at our feet; the Nymphs,
That press with nimble step the mountain thyme
And purple heath-flower come, not empty-handed,
But scatter round ten thousand forms minute
Of velvet moss or lichen, torn from rock
Or rifted oak or cavern deep: the Naiads too
Quit their loved native stream, from whose smooth face
They crop the lily, and each sedge and rush
That drinks the rippling tide: the frozen poles,
Where peril waits the bold adventurer's tread,
The burning sands of Borneo and Cayenne,
All, all to us unlock their secret stores
And pay their cheerful tribute.

J. TAYLOR, *Norwich*, 1818.

It is with great pleasure that I present my readers this month with the most complete catalogue of *American Official Geological Reports* ever published. The previous lists of Prime and Marsh have been consulted, but very many have been added during the period covered by Prime. Still it is incomplete, and I shall be very grateful to any one who will inform me of anything not included. In this connection the following recommendation from one who has bought many reports of me will be of interest:

Department of the Interior, United States Geological Survey. *Washington, April* 16, 1884.

A. E. FOOTE, M. D.,
1223 *Belmont Ave., Philadelphia, Pa.*

Sir:

* * * * *

If according to the last half of your letter it is of any service to you, you may say that the Librarian of the United States Geological Survey has had occasion to examine your whole stock in the search of rare reports, has purchased a good many books from you, and has found you in every respect a satisfactory person with whom to deal. In any case in which he desired a rare paper he should apply first to you before seeking elsewhere.

* * * * *

I am, sir, yours respectfully
CHAS. C. DARWIN, *Librarian.*

12 numbers of 32pp. each will be sent for every annual subscription.

NEW MINERALS RECEIVED.

Chalcopyrite in *tetrahedrons* from Pa. These are on a good solid base, and occasionally associated with fine octahedrons of Pyrite and Magnetite and beautiful fibres of bright green Byssolite. The tetrahedrons are often hollowed in a very interesting manner. These are undoubtedly the most interesting American Chalcopyrite specimens ever found. Fine specimens, $1.00 to $5.00.

Smaller specimens and good *separate crystals*, 5 Cts. to 1.00.

Octahedral Pyrite, some showing very interesting modifications and, rarely, twins from same locality, fine color, brilliant and beautiful, 5 Cts. to $3.50.

Byssolite from Pa. in calcite, the latter translucent and, rarely, transparent, also in tufts with Pyrite and Chalcopyrite. We have prepared a few specimens by eating out a little cup in the Calcite and the rim protects the tufts of Byssolite crystals that now fill the cup. 5 Cts. to $3.50. I also obtained this summer from Northern New York the best *Brown Tourmalines* I have ever had, one, the most perfect crystal I have ever seen, about 2 inches in diameter, remarkably brilliant and well shaped and on a marble base, price $10.00. The other, 4 inches high by 4½ by 3 and remarkably perfect and well shaped for its size though it has been indented more or less by calcite, $10.00. I have also smaller specimens 5 Cts. to $3.00 each, and black *Tourmalines*, some associated with green *Pyroxene* and *Quartz* crystals, at 5 Cts. to $5.00 each. *At Antwerp*, N. Y., I purchased the finest *Millerites*, *Siderites* and *Chalcodites* I have ever had. Specimens 5 Cts. to $5.00.

The most of my time spent in collecting this summer was devoted to *Canadian localities*.

The most important was the great *twin Zircon* locality which, from personal observation I am now convinced, is practically exhausted. I paid $25.00 for the largest twin ever seen on the gangue and have since spent over $5.00 worth of time in improving it. It is on a nice pink Calcite and Feldspar gangue 6 × 4½ × 3 inches. The twin is 2½ × 1½ × ½ inches, price $50.00.

copies had by then crumbled to acid-laden dust. The same fate has nearly overtaken *The Exchangers' Monthly*; therefore, after we have completed the careful scanning of every page of our set (which, happily, includes the original often-discarded wrappers with their ads), we intend to reprint 100 sets on cotton paper in order to preserve it from extinction. We hope eventually to be able to do the same for *The Mineralogists' Monthy* and *Minerals* if we can gain access to the issues we currently lack. If any reader knows of a library or private collection that contains copies of these old journals, please let us know, and perhaps we can arrange to borrow them for scanning.

In the meantime, we expect the Mineralogical Record's online Label Archive to be a continuously growing resource on the history of mineral collecting and dealing. We hope you enjoy it, and please contact us if you can offer any additional references, information on specific entries or scans of labels we don't have.

Art Museum Additions

While you are visiting our website, check out the new artists who have been added to the Art Museum section:

David Babulski, 62, is a long-time mineral collector and a professional educator in industry, having obtained both a Masters Degree and Doctoral Degree in science education. He has also been an artist since his youth, with an interest in combining his two favorite fields: mineralogy and watercolor painting. He specializes in the particularly difficult area of micromineral illustration.

Sarah Sudcowsky, 30, is an Italian professional illustrator from a long line of artists going back to her great-grandfather in Czarist Russia. She is also an avid field collector with a large personal collection and a fondness for pegmatite minerals, especially the minerals and localities of the island of Elba, where she has collected extensively. She specializes in fantasy art involving minerals, and has provided examples for us to post from her forthcoming book.

Viktor Slyotov, 51, and **Vladimir Makarenko**, 27, are Russian artists who often collaborate on individual artworks. Viktor holds a degree in mineralogy from Moscow State University and has exhibited his award-winning mineralogical art at the Fersman Museum in Moscow as well as at the Russian Academy of Art. His personal mineral collection of over 2,000 specimens (from which he draws his subjects for paintings) is chosen to illustrate the morphology and ontogeny of minerals. Vladimir is a career artist and graduate of the Tver College of Art who has also won awards in Russia. After meeting Viktor he became fascinated with the problems of depicting the mineral world artistically. They are currently collaborating on the *Ontogeny of Minerals in Drawings* publishing project, now in its third volume. The drawings and paintings they present combine a scholarly structural and genetic approach to minerals with the fine-art feeling of beauty encountered in individual specimens and crystal aggregates, reviving the best mineralogical traditions of the past by portraying both scientific and artistic elements of the mineral world.

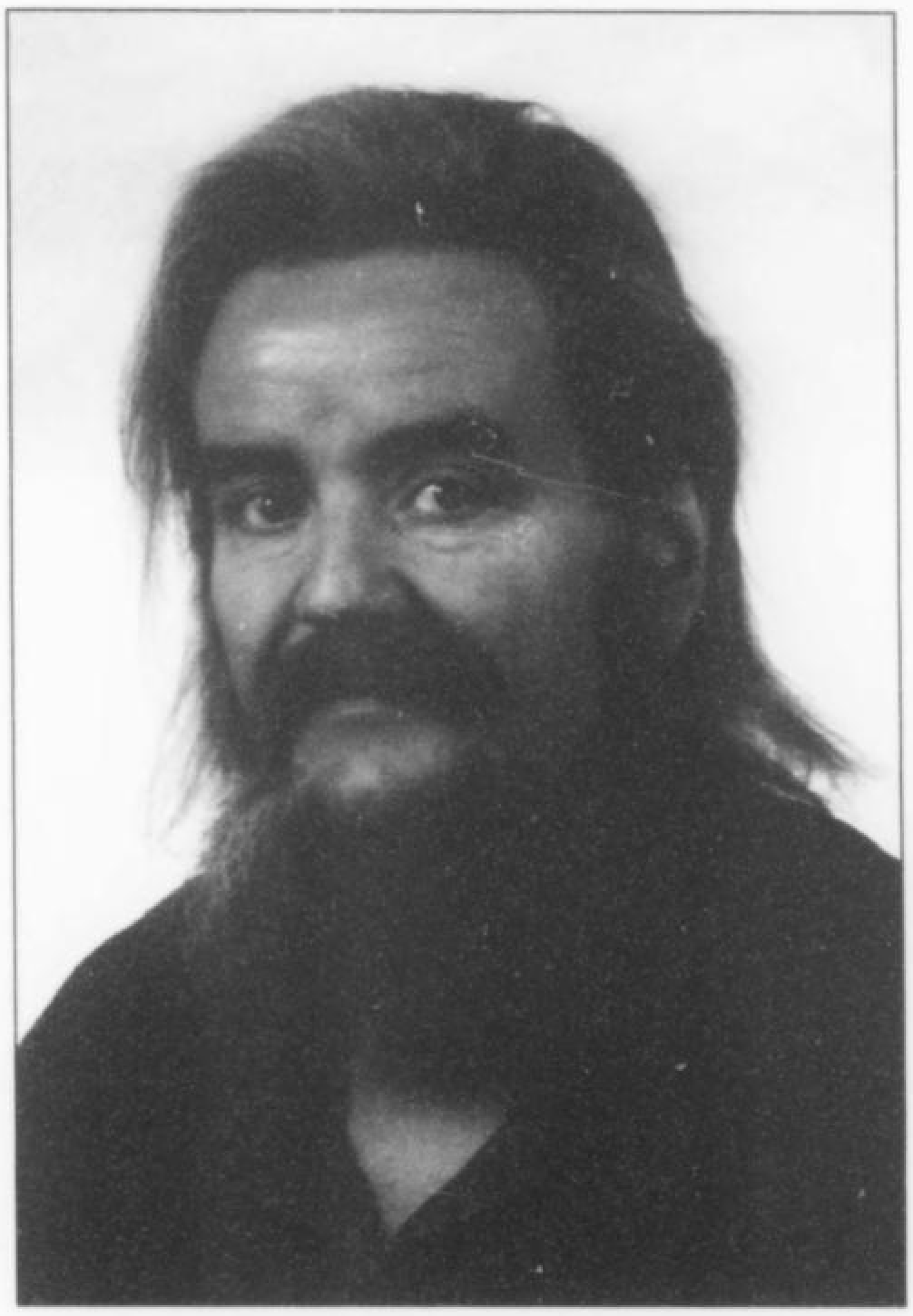
Died, Maximilian Glas, 57

Maximilian Glas was a gifted artist, a co-founder of *Lapis* magazine, a graphic designer for many mineralogical publications including the Munich Show catalogs, and an enthusiastic mineral collector. He was born in Bad Wörishofen, Bavaria on March 7, 1948, and succumbed to a grave illness on November 4, 2005.

At the age of eight Max was sent to Sankt Blasien, a Jesuit boarding school in the Black Forest. It was there that he received a humanistic education and had his first contacts with mineralogy thanks to the school's mineral collection and the influence of the father of one of his fellow classmates. After graduating from secondary school, he spent nearly a year acquiring practical experience at the Gottesehre ("God's Honor") mine, a small fluorite mining operation in Urberg, near Sankt Blasien. Afterwards he studied mineralogy at the universities in Berlin and Freiburg.

I first met Maximilian in 1972. Our professional collaboration began in the winter of 1974/75, when he and Hartmut Schmeltzer collaboratively designed a guidebook to the mineral collecting sites of Baden-Württemberg, Bavaria and Rhineland-Palatinate. Maximilian and I then co-founded *Lapis* magazine in 1976. Our goal was to publish a periodical patterned after the *Mineralogical Record*, which was our role model. We wanted to create a scientifically precise yet readily comprehensible and, above all, beautifully illustrated publication, a periodical that would be entirely different from the club publications that were available in Europe at that time. Maximilian transformed our ideas beautifully into a tangible reality, and he did so with his characteristic attention to detail, his profound mineralogical expertise, and his sensitivity and talent as a graphic artist.

He left the publishing house in 1979 to embark on an extended journey through Greece. Afterwards he directed an African music ensemble and designed the show catalog and advertising for the Münchner Mineralientage (the Munich Show). In 1991 a spontaneous idea led to the birth of the *ExtraLapis* series. Maximilian was once again wholly in his favorite element. He devoted many long evenings to the discriminating task of fine-tuning the *ExtraLapis* concept.



Maximilian Glas (1948–2005)

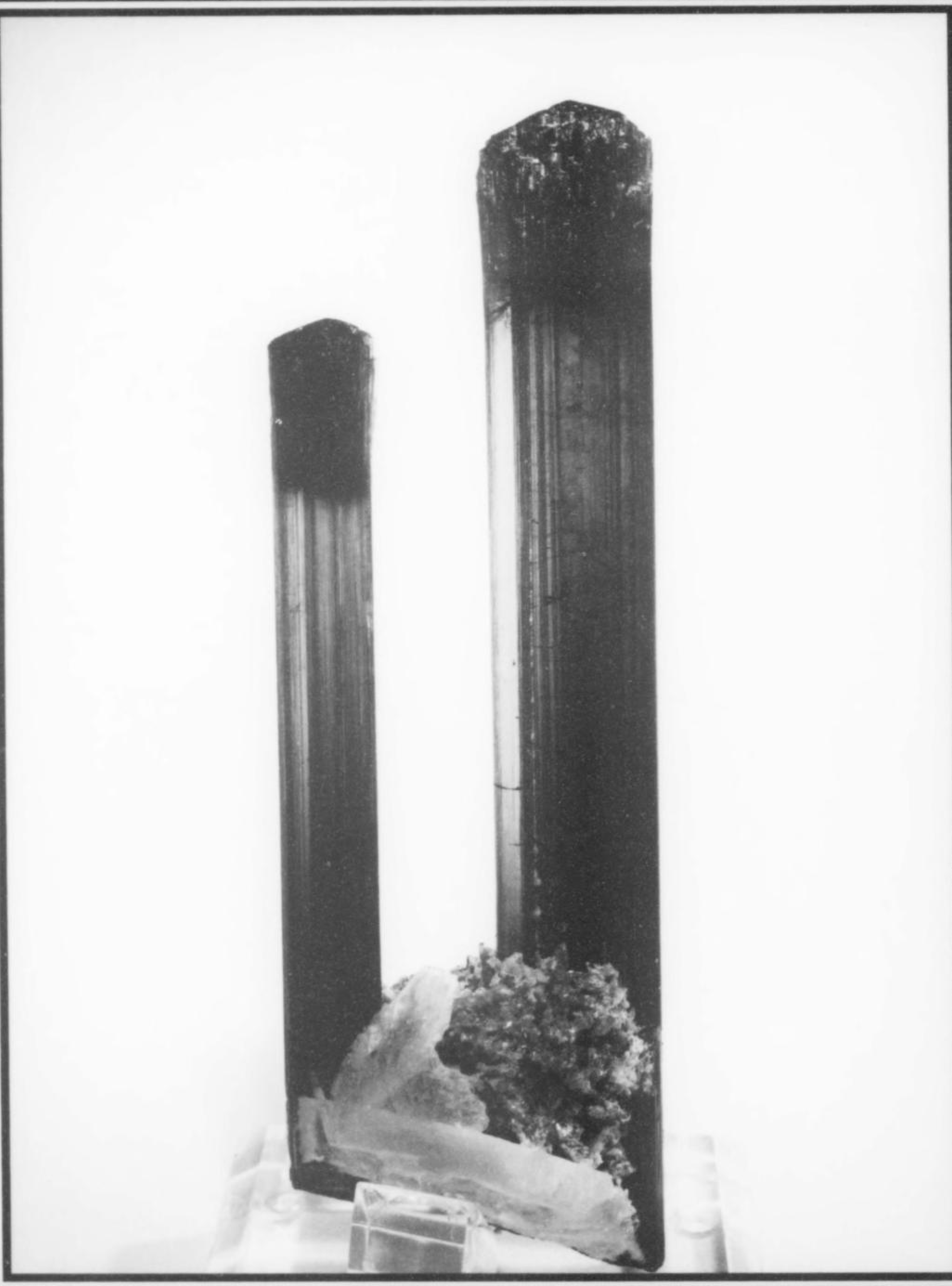
In addition to the aforementioned catalogs for the Munich Show, he also designed the most outstanding book project in our scientific specialty: Friedrich Benesch's extraordinary full-color, oversize volume *Der Turmalin* (1990). Maximilian's enthusiastic devotion to this theme prompted him to begin acquiring a diverse and interesting tourmaline collection. His style and artistic signature are likewise obvious in other book projects, e.g. Ulrich Dernbach's *Araucaria* (1992), Konrad Götz's *Lichtgestein* ("Stone Light") (1998), Roland Schlüssel's *Mogok* (2002), Anselm Spring's books *Holz* ("Wood") (1999) and *Stein* ("Stone") (2001), and many others. To mention all of the many book projects to which he contributed would be impractical here.

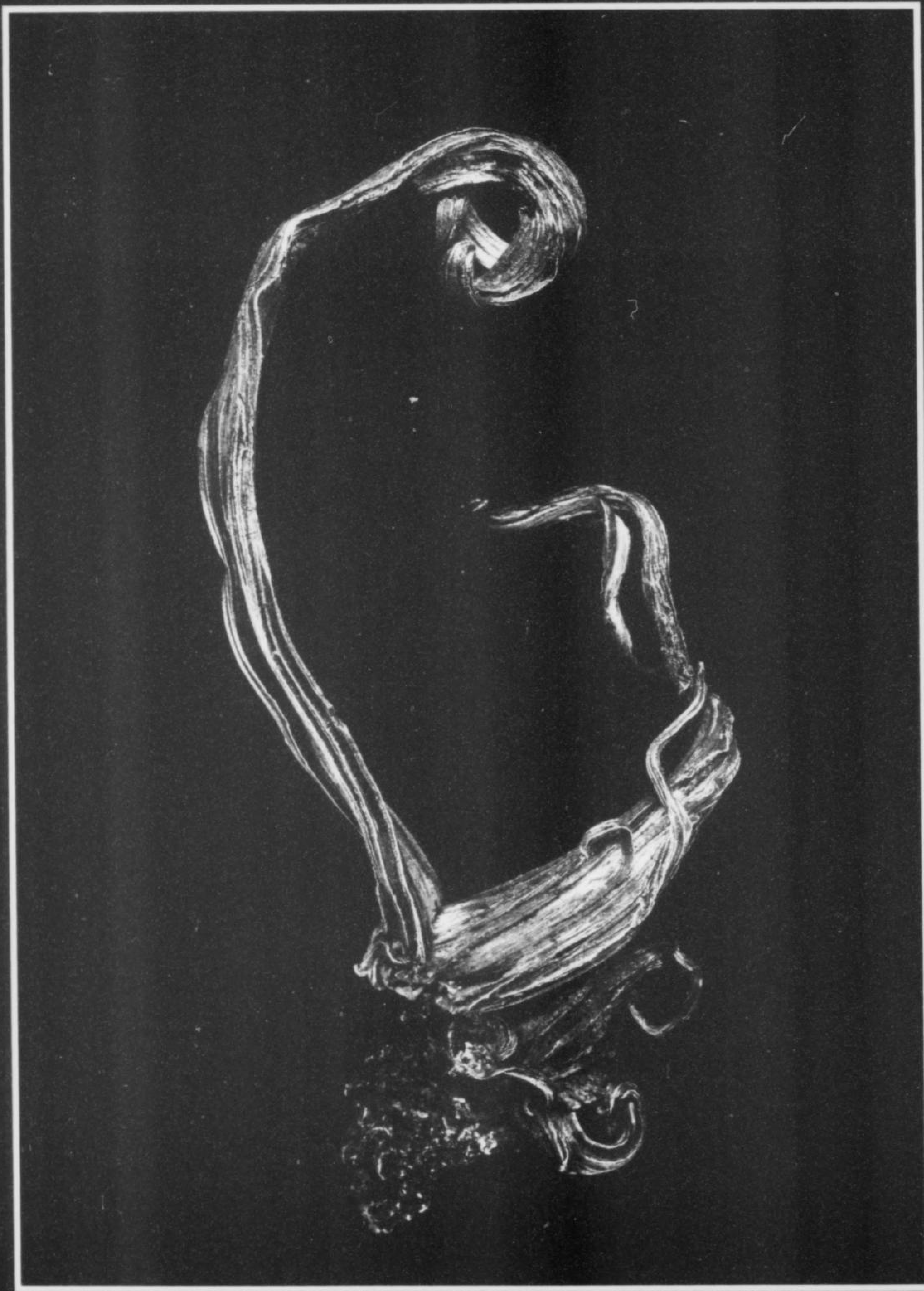
Why was Max repeatedly able to create something wholly new and unexpected? Alongside his superlative gifts as a graphic designer, I think the most important reason lay in the fact that he was always incredibly open-minded and eager to explore whatever was new and unfamiliar to him. All of his senses were always wide awake, and he was the best listener I've ever known. These traits naturally contributed to his exceptional creativity.

Max was extraordinarily well read. He was practically a walking encyclopedia in many fields of knowledge. And he was largely self-taught; formal study according to predefined educational curricula simply weren't Max's cup of tea. Although he had never undergone formal education in the graphic arts, Max was the best graphic designer I've ever had the privilege to know personally. And despite (or rather thanks to) his exceptional talents, he was never the slightest bit pedantic or supercilious. His relationship to mineralogy was only one of his many facets. Music, which accompanied him throughout his life, was his earliest career wish.

The many traces that he leaves behind will help to keep him fresh in our memories forever and assure that he'll abide eternally in our midst. One can rightly and justifiably say that he contributed a tremendous amount of culture and aesthetics to our mutual métier.

Christian Weise, Munich
(translation by Howard Fine)





SILVER, 14.8 CM, FROM KONGSBERG, NORWAY

Famous Mineral Localities:
Llallagua, Bolivia

Jaroslav Hyrsl
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Llallagua, once one of the world's richest tin deposits, is one of the most important mineral localities in South America. It is the type locality for five mineral species (vauxite, metavauxite, paravauxite, sigloite and jeanbandyite) and has also produced some of the world's best specimens of stannite, cylindrite, monazite, bismoclite, and other species. The mine is still in operation and specimens continue to be found in the upper levels.

INTRODUCTION

Llallagua is a tin deposit located at an altitude of more than 4,000 meters (13,000 feet) in the eastern Andes Mountains in Bustillo Province, northern Potosí department, Bolivia. It is located about 75 km south-southeast of the town of Oruro and about 270 km south-southeast of La Paz. In the middle of the 20th century Llallagua was the most famous and productive tin mine in the world; it is now past its peak, but mining is still active, and new specimens often reach the collector market in North America and Europe.

Llallagua specimens may appear in collections under several loosely interchangeable locality names, including "Llallagua," "Siglo Veinte," "Siglo XX," and "Catavi"—all of these names refer to the *same* locality! Llallagua (pronounced "yah-YAH-wa"), the term most commonly seen on specimen labels, refers to the city in which the mine is located. *Llallagua* (according to Gordon, 1944) is the Quechua Indian word for "mammae" or "twin peaks." Catavi was both the name of the nearby mill and the name of the administrative division of COMIBOL (the State mining corporation) which controlled the mine during the years when it belonged to the State. Siglo Veinte, or Siglo XX (= "Twentieth Century" in Spanish) is the actual name of the mine, commemmorating the fact that it was opened at the beginning of the 20th century. Other terms that may appear on labels, especially in local Bolivian collections, are "Salvadora," for the mountain which hosts the orebody, or the names of individual *Secciones* (Sections)—miner-owned cooperatives on different parts of the mountain—including "Cancañiri," "Dolores" and "Dolores Atrás." Further compounding confusion for foreigners, Bolivian collectors often write only the name of an adit or vein on their labels, omitting the mine name; for example, an old monazite specimen in the San Diego Natural History Museum, labeled simply "San José" is from the San José vein at Llallagua, not the famous San José silver mine in Oruro city.

Figure 1. **Location map showing the important Bolivian tin and silver mines in La Paz, Oruro and Potosí Departments.**

HISTORY

Llallagua is much richer in tin and poorer in silver than the similar subvolcanic deposits of Potosí and Oruro (Hyrsl and Petrov, 1996). Nevertheless, silver was mined in Llallagua in the early 19th century (Bandy, 1944), although it is not known what the silver ore minerals were, and reports of native silver can no longer be substantiated. Since minerals containing essential silver are present only as insignificant traces (e.g. andorite), the silver ore minerals may have been franckeite and stannite (both of which commonly bear a few tenths of a percent silver), and sphalerite with micro-inclusions of tetrahedrite. In the late 1990's, a galena vein with minor pyrargyrite was worked in neighboring Uncia, on the southeast side of the mountain, and it is possible that such veins were found extensively during the early 19th century but have been obliterated by mining. In any case, the earliest published reference to minerals from the mine appears to be a note by Arzruni (1884) describing cassiterite crystals that had been obtained in Llallagua. The earliest account of the mine itself is Stelzner (1897).

The modern history of Llallagua begins with prospecting for tin at the end of the 19th century and soon thereafter becomes entangled with the career of *Simon Iturbi Patiño*, one of the most remarkable men in Bolivian history. Patiño was a mestizo born into humble circumstances in 1868 in the village of Santibañez outside Cochabamba city. According to a wide-spread story, he was working as an assistant in a rural general store in Cochabamba when, around 1900, he made a modest personal loan to a tin miner and received in return the deed to a small tin mine called Juan del Valle, on the southeast side of Mt. Salvadora in Llallagua. He moved there in 1903, did some digging with his wife, and soon found a cassiterite vein which turned out to be fabulously rich. He opened his first mine on the southeastern side of the mountain while a Chilean company, "Compania Minera de Llallagua," was operating a mine on the northwest side. Already by 1905 Patiño's company had become one of the most important in Bolivia, and was beginning to buy up all of the other properties in Llallagua. By 1924, when he finally bought out the Chileans, forming "Patiño Mines & Enterprises Consolidated," he was well on his way to becoming one of the wealthiest men in the world.

Little by little Patiño acquired other important Bolivian mines (e.g. the Huanuni tin mine and Kami tungsten mine), as well as tin mines in Malaysia and even tin refineries in Europe. Along with Moritz (Mauricio) Hochschild and Franz Aramayo, he became one of the three so-called Bolivian "tin barons" who in some ways were more powerful than the State itself. In the decades before the mines' nationalization in 1952, the mining conglomerates run by these three men accounted for approximately 70% of all Bolivian mineral exports by value. Under the leadership of "the barons," tin mining reached its historic peak in 1929, when Bolivia produced 49,191 metric tons of the metal.

It is fortunate for the scientific record that, over the years, three very competent mineralogists have been able to study the Llallagua minerals on site and have published their observations. The first was the American mineralogist **Samuel Gordon** (1897–1953) (see

Figure 2. **Simon Iturbi Patiño (1868–1947), one of the great Bolivian "tin barons," who rose from poverty to become one of the wealthiest mine owners in Bolivia and the owner of the Llallagua mine (nationalized five years after his death).**

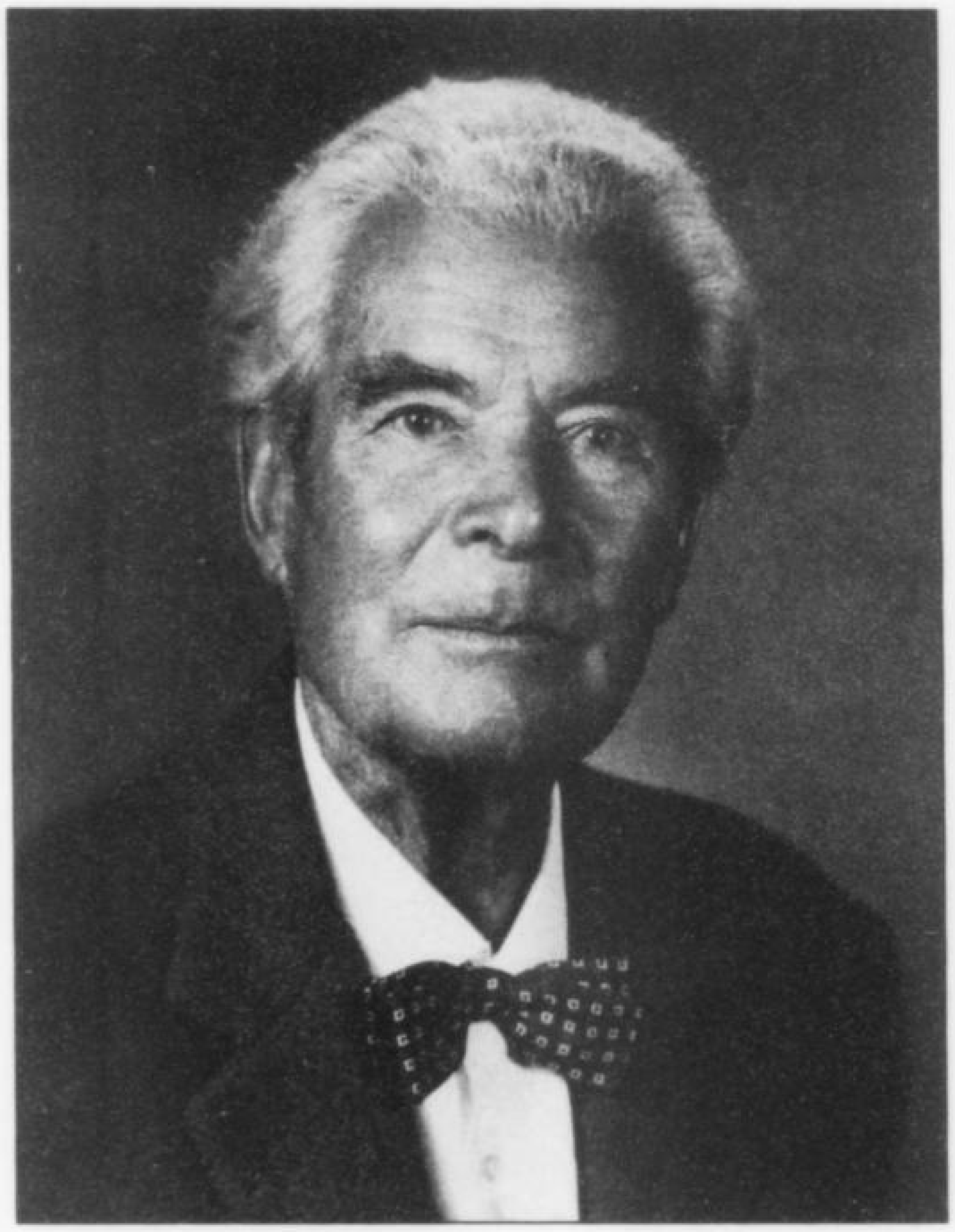


Figure 3. **Fredrich Ahlfeld (1892–1982), the "Father of Bolivian Geology" and the author of important studies which included the mineralogy of Llallagua (photo courtesy of Manfred Ahlfeld).**

Montgomery, 1973–1975), who visited the mines on behalf of the Philadelphia Academy of Natural Sciences in 1921, 1925 and 1929 specifically to study the mineralogy and collect specimens for the Academy. He visited over 100 working stopes, as well as examining remaining pillars of ore in abandoned but still accessible stopes. He personally collected a great many specimens, and was given more by miners and engineers. These he brought back with him to Philadelphia where he carried out detailed analyses, especially including goniometry which yielded many crystal drawings. His trips were described in the Annual Reports and Yearbooks of the Academy in 1922, 1926 and 1930, and he published all of his mineralogical findings in his monograph *Mineralogy of the Tin Mines of Cerro de Llallagua, Bolivia* in the Academy Proceedings in 1944.

The second mineralogist of note at Llallagua was **Friedrich Ahlfeld** (1892–1982), "the Father of Bolivian geology," who served in Bolivia as Chief Geologist for the Bolivia Government in 1935–1936 and 1938–1946, and worked for Patiño Mines and Enterprises (operators of the Llallagua mine) from 1951 to 1952. He published numerous works that dealt in part with the mineralogy of Llallagua, most prominently his 1937 book with Jorge Muños-Reyes, *Los Minerales de Bolivia* (now in its sixth edition) and his 1941 and 1954 books on the mineral deposits of Bolivia.

The third important investigator was the American mineralogist and mining engineer **Mark Chance Bandy** (1900–1963), who worked for the Patiño company from 1936 to 1947. Much of that time he spent working at Llallagua, where he progressed from Chief Geologist to Chief Engineer to General Manager, all the while making careful records of the many mineral occurrences encountered in the course of mining, and amassing a superb personal collection of Llallagua minerals (later donated to the Natural History Museum of Los Angeles County; see Jones, 1973). Bandy published the results of his work in his 1944 monograph, *Mineralogy of Llallagua, Bolivia*. The works of these three authors form the basis of the current review, augmented by information on more recent finds known to the current authors.

By the end of the 1930's, Patiño's companies controlled more than 60% of the world's tin business. But Patiño himself had moved to Europe in 1912, and ran his empire from there, seldom returning to Bolivia. (His children intermarried with European nobility, and his descendents presently live in Switzerland and France.) Simon Patiño died in Buenos Aires in 1947, and his tin empire passed into his children's hands—but only for the next five years.

Block-caving was introduced in 1950 and Siglo XX became the largest, most productive and most modern tin mine in the world. But many Bolivians resented the fact that the wealth generated by Bolivia's tin was being frittered away in Europe, and rebellious sentiments simmered. In 1952 came revolution and nationalization, and the Patiño family lost all of its Bolivian mines (although the overseas portions of its empire lasted much longer). The Siglo XX mine fell under the control of the State mining corporation, COMIBOL (Corporacion Minera de Bolivia).

The first few years after the revolution were trying times for the mine engineers, laboratory workers and other technical staff, because the miners' unions enjoyed enormous political power despite their members' lack of education and technical expertise.

Figure 4. **Mark Chance Bandy (1900–1963), General Manager of the Llallagua mine in the 1940's, author of an important review of Llallagua mineralogy (1944) and the builder of an important collection of Llallagua minerals now in the collection of the Natural History Museum of Los Angeles County.**

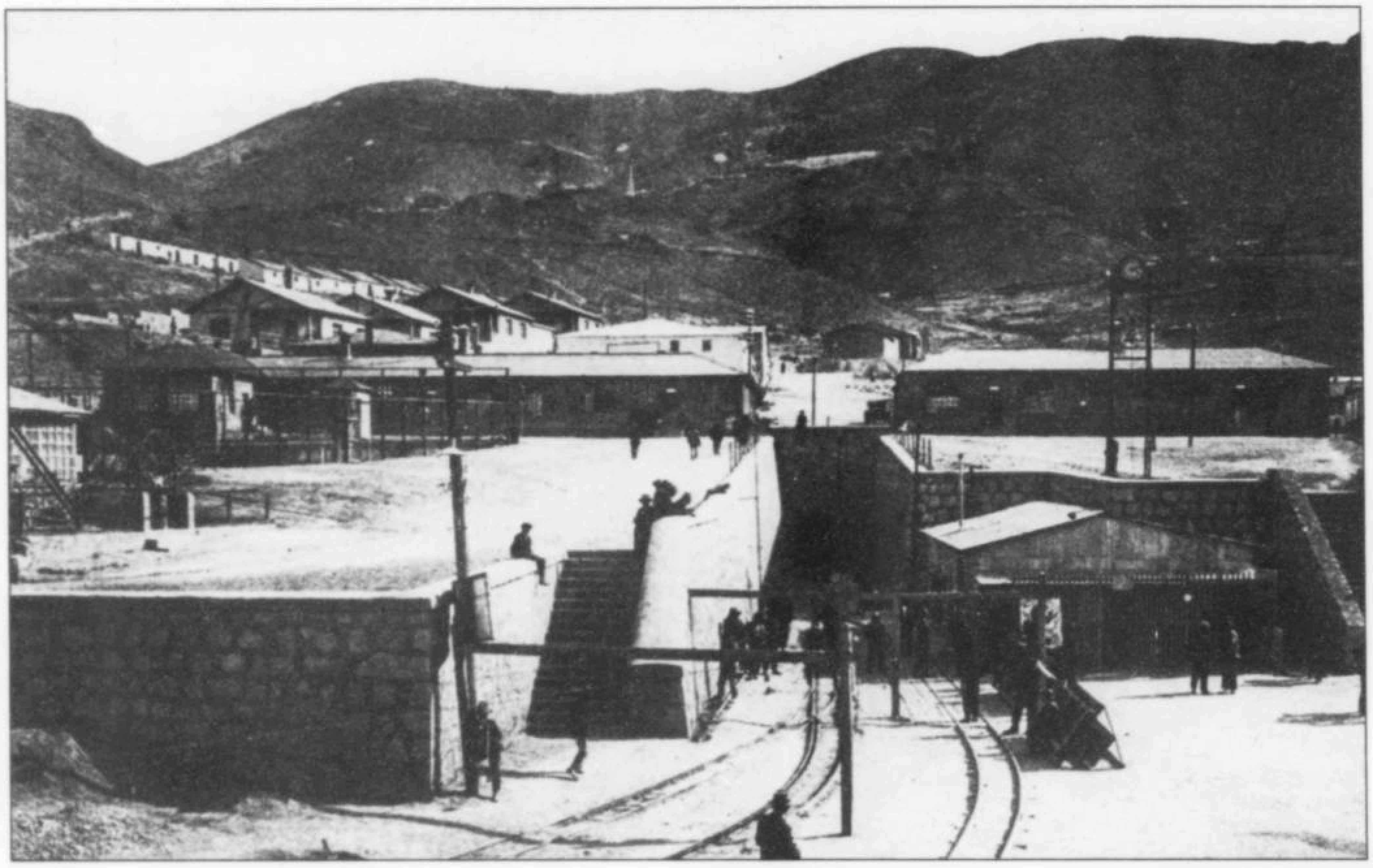


***Figure 5.* The portal of the Siglo XX Tunnel and surrounding mine buildings in 1937 (photo from Deringer and Payne, 1937).**

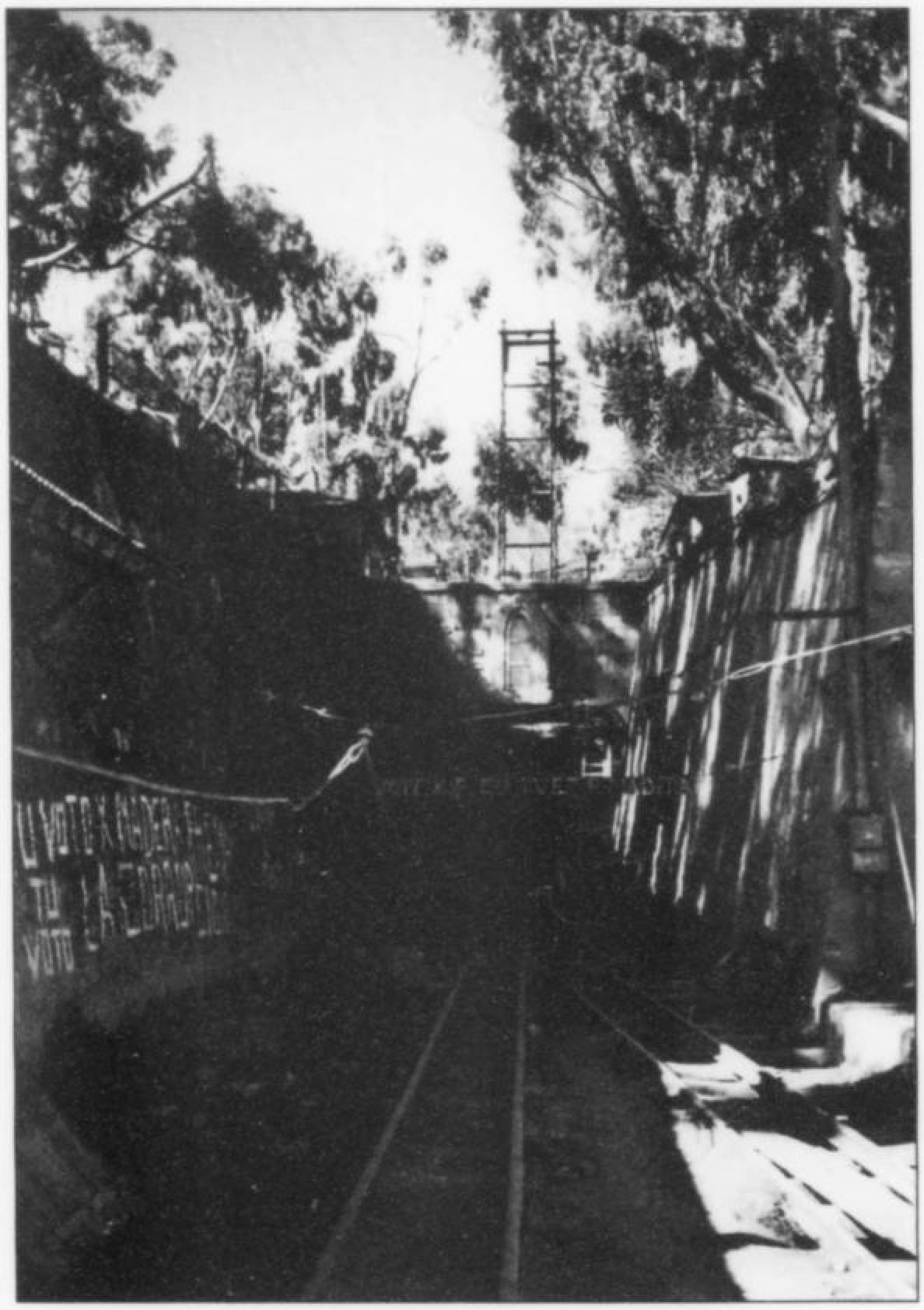


***Figure 6.* The portal of the Siglo XX Tunnel today. Hyrsl photo.**

Administrative and technical departments were forced to take miners onto their staffs (reportedly with disastrous effects on laboratory glassware). Strikes and violence were frequent, with many miners supporting the Communist party. Llallaguans tell stories about politically active miners hiding underground for weeks at a time in remote galleries when the police or army came looking for them, their wives smuggling food down to them by way of forgotten adits and stopes.

In the 1960's another problem arose: theft of ore by organized bands of hundreds of *jucos* (from the Quechua word for "nocturnal raptor"). The *jucos* were unemployed miners who created fictitious mining claims on other mountains but in reality were sneaking into the Siglo XX mine to highgrade cassiterite and sell it to Llallagua's COMIBOL-owned Catavi mill. The ex-miners were soon joined in this *juqueo* by thousands of indigenous *campesinos*, increasing the headache for COMIBOL. Cornelius Bloot, the Dutch general manager at Catavi, knew very well what was going on, but he bought the *jucos'* concentrates anyway, partly out of compassion and partly out of pragmatism: he knew that the *jucos* would just sell the concentrates to another mill if Catavi refused to buy them. Eventually COMIBOL resigned itself to turning a blind eye to *juqueo*, which provided concentrates to the mill more cheaply than COMIBOL itself could—and there was no need to provide medical or other benefits to the poor *jucos*!

The great days of commercial mining at Llallagua were ending in any case. The world price of tin had been falling since the end of World War II, the politicians sucked up any profits from tin exports without leaving much for COMIBOL to reinvest, and COMIBOL was awash in red ink. So COMIBOL finally left Llallagua in the mid-1980's and handed the mines over to the local miners. By this time the mountain was honeycombed with more than 800 kilometers of galleries.

At present, about 5,000 miners still work at Llallagua, but conditions are much deteriorated from the modernity of the 1950's and 1960's. The mountain is owned by five cooperatives of mostly indigenous miners, working with no capital and little technical support; these miners earn as little as $60 per month. Trains, hoists and crushers no longer work. Miners carry ore out in rucksacks, crush it by hand with curved steel rockers, and concentrate it

(continued on overleaf)

Sam Gordon at Llallagua, 1925 and 1929

[*The following is an excerpt from Sam Gordon's report on his 1925 expedition to Bolivia, published in the* Philadelphia Academy of Natural Sciences Yearbook *(1926).*]

On Monday morning [in Oruro, Bolivia] I worked my way through the dense crowds at the station to the Llallagua train. With much ceremony, a bell was rung, and the train departed. Toward noon we passed the mines of Huanuni, stated to be the first mines worked for tin in Bolivia. It was late in the afternoon when the train reached the mines of Llallagua. These mines produce about fifteen percent of the world's annual supply of tin, as well as considerable bismuth. The tin veins are associated with a large mass of quartz porphyry which has been intruded into a fine-grained red sandstone.

While at Llallagua I made my headquarters at Catavi, the site of the mill, about a league distant from the mines. Daily, after *desayuno*, or breakfast, I mounted a mule and swung into the trail across the barren, monotonous pampa, broken here and there by an occasional ravine. Just below the mines is the native village of Llallagua, pungent with the odor of burning llama dung from the braziers of the Indian households.

At the main tunnel, the Siglo XX, the *chico,* or boy, prepared the mine lamps. Seating ourselves on the electric locomotive, we were rushed into the tunnel for a distance of two miles—a trip made in six minutes—to the main shaft. Huge rooms had been cut into the rock, and the walls echoed with the staccato roar of the drill dressers in the blacksmith shop, and the rhythmic boom of the air compressor. Stepping into a cage, we were whisked up to one of the principal levels. Numerous drifts and cross-cuts radiated out to various veins. We walked out along a track, stepping aside now and then to avoid a passing ore car, until we came to a place where we could enter a stope.

To those not familiar with mining methods, a word of explanation of stoping will be necessary. Tunnels are driven along the veins at vertical intervals of a hundred feet. These are roofed over with heavy timber. The ore in the vein is then blasted down onto the roof of the tunnel. At intervals in the roof are chutes through which the ore can be dropped into ore cars. The miners begin at the roof of the tunnel and gradually work upward until all the ore in that section of the vein has been broken up to the next tunnel level, a hundred feet above. Such a working is called a stope.

If a stope has just been started the climb is short. However, where there has been considerable stoping, a climb of 40 or 50 feet may be necessary, or it is sometimes feasible to climb down from an upper level. Several means of access were used, differing in the amount of gymnastics required. We considered ourselves fortunate if there was a series of ladders in various stages of completeness. Missing rungs were frequent, and the reason was apparent. One morning we climbed across a space where a vein had been stoped out. On reaching the opposite end of the ladder we found that it was held in place by a single nail. The next night a fall of rock sent it crashing to the bottom. Sometimes the wooden ladder would be replaced by one of swinging rope. But not infrequently we had to haul ourselves up a rope, bracing the back, knees and elbows against the rock sides. Loud shouts of *"Guarde ariba!"* ("Look out above!") announced our entry into the raise, so as to avoid being greeted with a shower of rock or drill steel.

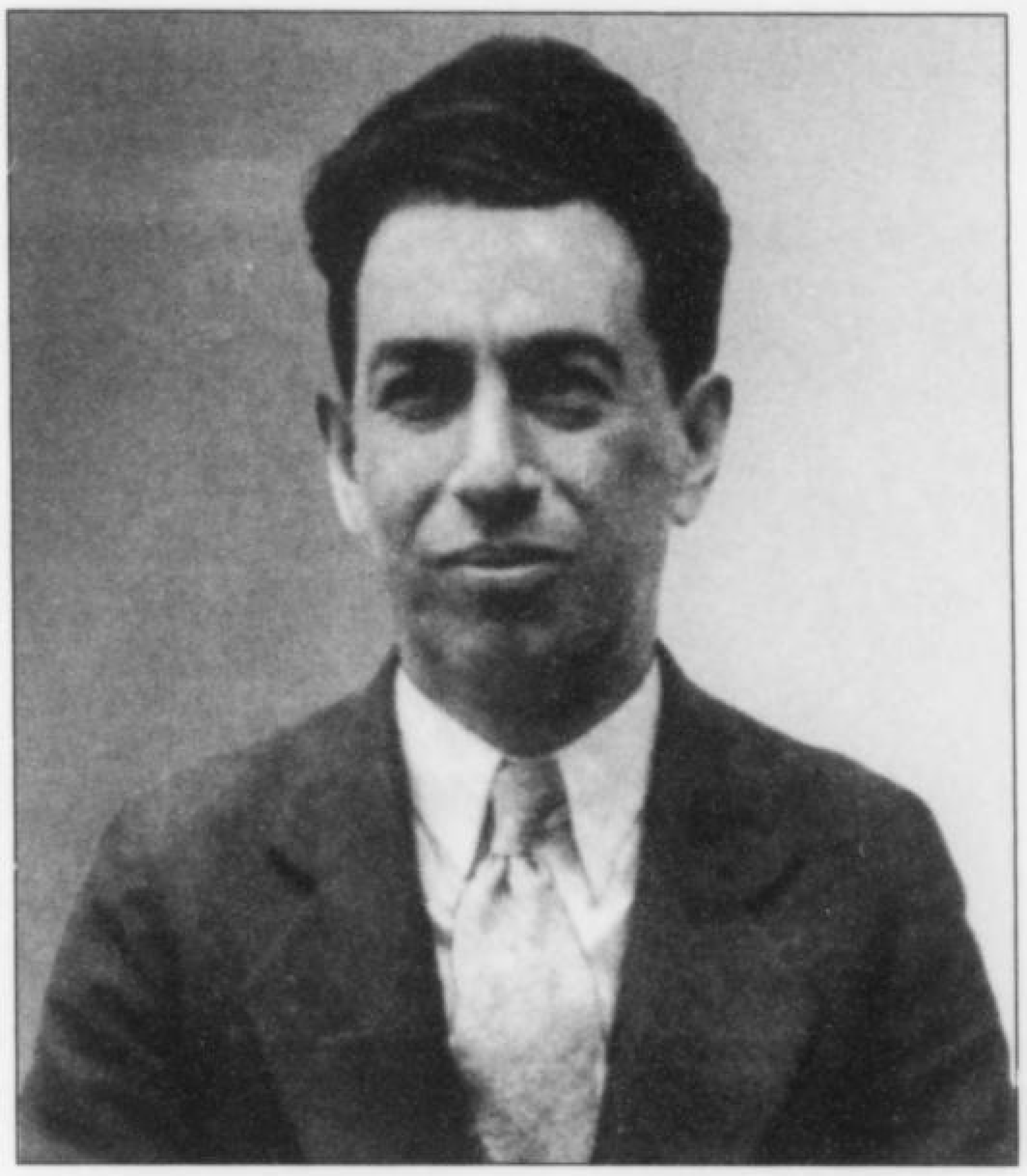


Figure 7. **Samuel Gordon (1897–1953), a mineralogist for the Philadelphia Academy of Natural Sciences, prepared the first detailed studies of Llallagua mineralogy (published in 1944) based on specimens collected there during Academy-sponsored expeditions in 1921, 1925 and 1929.**

The stopes presented scenes of great industry: Stolid Quechua Indians were operating compressed air drills, or were loading holes with dynamite for the noon or late afternoon blasts. Making our way over the rough floor of broken ore, we carefully examined the face of the vein overhead, and the rock walls on each side. The ore consisted largely of cassiterite, SnO_2, in black crystals or masses through quartz, associated with some bismuthinite and wolframite, and much pyrite. Small cavities were lined with twinned crystals of cassiterite. The bismuthinite formed long blades shooting through the pyrite, sometimes with apatite and vivianite. We were surprised at the large amount of the rather rare mineral wavellite, which occurred in druses of colorless crystals covering quartz crystals, or lining fractures along the walls. A single vein of vauxite and paravauxite was found in one stope.

At noon we returned to the surface, and hustled to the dining room, presided over by a smiling Japanese. The meal was enlivened by a discussion of the specimens, and of plans for the afternoon. After eating we wandered over the *cancha* (mine dumps). Groups of Indian women sat around piles of ore, breaking it up with heavy hammers, and rejecting the worthless material. At one o'clock we re-entered the mine. In a single day from four to seven stopes were visited. At 4:30 p.m. we gathered for tea, which was usually followed by a game of tennis before returning to Catavi.

Some difficulties were encountered in visiting the more remote portions of the mine. The examination of one vein involved climbing down through 875 feet of stopes in a single morning, over 500 feet of which were by ladder. Other veins could only be visited by being lowered down a shaft by means of a steel cable at the end of which were two iron hoops into which the legs were thrust. Descents of 300 feet were made in this manner. In three weeks all of the working stopes were examined in the more than 50 miles of tunnel in the mine. Fifteen cases of specimens were collected, labeled, and packed in steel-strapped boxes. They were then sewn in burlap for shipment.

[*The following is an excerpt from one of Gordon's letters to his financial backer for the trips, Mrs. George Vaux, Jr. (widow of Gordon's good friend George Vaux), written during his 1929 expedition to Llallagua.*]

My dear Mrs. Vaux,

Bolivia now lies behind me, and the first part of the trip is over. The two months spent there have been extremely fruitful, as is evidenced by sixty-three (63) boxes of specimens, or almost as many as the total number obtained on the last two expeditions to the Andes combined.

The principal minerals have been the vauxite group: vauxite, paravauxite, and metavauxite. Not only has enough material for research work in the chemistry and physical properties of the group been obtained, but also a fine series [of specimens] for both collections. And there are enough choice duplicates of paravauxite to supply all of the collections of the world. The paravauxite and metavauxite are superior to anything obtained before. In fact, the previously collected material is just junk. There are enough fine duplicates, particularly of paravauxite, to pay the entire costs of the expedition so far; and most institutions will be glad to get some of the material.

From Oruro, where I last wrote to you, I went to Llallagua. The mines are much larger now, and there are today over 110 stopes and some 120 miles of workings. In the three and a half weeks here I went pretty thoroughly through the mine. You remember that last fall the assistant mine superintendant brought up some specimens. Well he has been keeping his eye open since then. The General Manager told him I was coming to Bolivia, so he renewed his efforts, most commendably, to gather specimens. He told the metallurgist, "Gordon is coming down next month, and I have the finest collection of vauxite, paravauxite and metavauxite in the world; and if he wants it he will have to come across with $1000." He stated that he knew where there was another big vug that he was going to empty.

The metallurgist then asked a young engineer he knew who had charge of a richly mineralized section of the mine if he had seen any paravauxite in the mine. Sure, he knew where there was a fine vug of the mineral. It seems that the engineer had seen the assistant mine superintendant stop there and dig out a specimen. So the young engineer got busy and filled up half a dozen boxes of vauxite. Then I came along. He told me a story about how some former workman had found it and wanted to sell it, [while] keeping secret which part of the mine it was found in. After a couple of days (during which he steered me away from this section of the mine) I bought his lot for $103. It was wonderful stuff, and although I felt that I might come across the vug myself later, I wanted to gather in every scrap to avoid any of it getting to Ward's or any other institution.

The next day, after I had packed up the previous purchase, he said that the man had brought in another lot. This was somewhat better, and I bought it for $175. Meanwhile I steered clear of the assistant mine superintendant, and bided my time before attempting to purchase his vivianite, metavauxite and vauxite. He realized that his competition had ruined his price. I got his stuff toward the end for less than $350, or about a third of his original price.

So, having cleaned these fellows out, and gone pretty well through the mine, I decided to look for the lost paravauxite vug. One day the young engineer said he was not going into the mine. So at 9 o'clock I headed for his section, picking up a boy at his office to carry the bag. I knew about where the cross-vein should be, and felt quite sure it was on the 195 level. Within half an hour I had found it. The engineer thought he had cleaned it out. Several large chunks of rock blocked up the entrance. After an hour's work I had it well opened up, in such shape as to get out some fine specimens. When I left Llallagua, I shipped 49 boxes of specimens back to Oruro.

themselves with buddles. If Georgius Agricola were to visit Llallagua today, he would feel right at home!

The total amount of tin produced by the Siglo XX mine is unknown, but it had already yielded about 500,000 tons by the early 1960's (Ahlfeld and Schneider-Scherbina, 1964). At various times the mine also produced lesser quantities of silver, tungsten (mostly during World War I) and bismuth (mostly in 1923–1925).

GEOLOGY

Cerro Salvadora, the mountain in which the Llallagua tin deposit is located, is a conical subvolcanic stock of Tertiary age, similar to the stock deposits of Potosí and Oruro. The Llallagua deposit crops out as a 1.1 × 1.7-km ellipse on the surface; narrowing with depth, it measures 1 km × 700 meters at a depth of 650 meters below the peak of Cerro Salvadora. It is made up of porphyry and porphyry breccia, having probably originated as an explosive vent. Llallagua's stock, also like Potosí and Oruro, is heavily altered, and almost all of the original feldspar in the volcanic rock has disappeared, having been replaced by quartz, sericitic muscovite, clay, tourmaline, pyrite and other minerals. However, tourmalinization played a much bigger role at Llallagua than at Oruro or Potosí: Llallagua may represent the world's largest deposit of tourmaline (although the tourmaline found there is mostly microfibrous, and there is no gemmy material). The intrusion was sericitized, tourmalinized and silicified before any of the ores were deposited. The prior silicification of the wall rocks prevented the ore-forming solutions from penetrating and replacing the porphyry, so the bulk of the ore was deposited in open shear zones and fissures.

Forty-seven main veins and approximately 1500 small but rich veins are known in the deposit, most of them trending northeast-southwest. Most of the tin ore was produced from veins transecting the volcanic stock, although some of the veins (e.g. the Contacto, Plata, Bismarck, and San Fermin) extend into the surrounding sedimentary rock, and the Carnevalito lies entirely in the sediments. The Contacto vein, perhaps the most important for mineral collectors, got its name from the fact that it crosses the contact

Figure 8 . **The road coming into Llallagua; note stockpiles of lumber for mine timbering. Rock Currier photo, 1975.**

between the igneous intrusion and sedimentary country rock.

Llallagua is a classic example of a "telescoped" deposit, in which high-temperature minerals (especially cassiterite and pyrrhotite) have been deposited in a low pressure, near-surface (xenothermal) environment. Low-temperature (kryptothermal) sulfides were later superimposed in the same veins, resulting in the characteristic complexity of Llallagua mineralization.

The principal access tunnel, Siglo XX, situated at the border of the town, runs along Level 650 beneath Cerro Salvadora; the richest mineralization was found below this level. (Levels in Siglo XX are customarily designated by the number of meters below the peak of Cerro Salvadora.)

The first depositional stage of the veins is represented by quartz, tourmaline, bismuthinite and cassiterite, with minor wolframite and fluorapatite. Some of the veins were fabulously rich. Turneaure (1960) mentioned that the San José/San Fermin ore shoot, which had a maximum stope length of 700 meters, with ore extending for 600 meters vertically, in many parts contained 25% or more of tin.

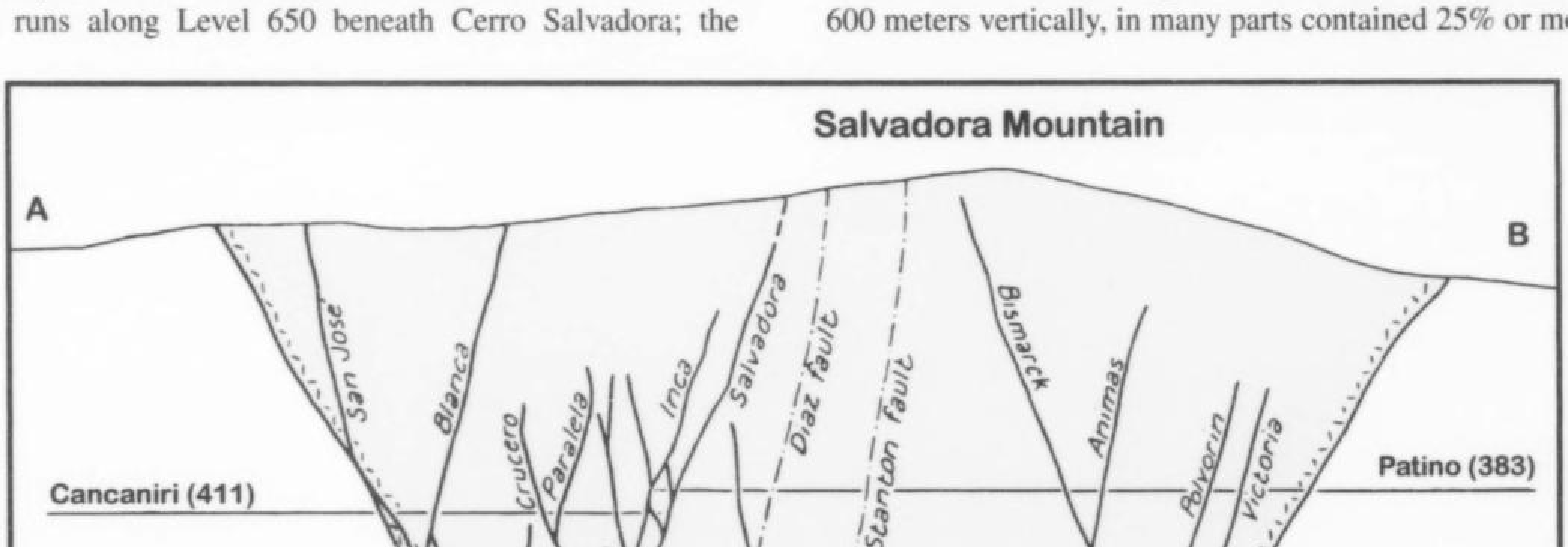


Figure 9. **Longitudinal cross-section through Salvadora Mountain showing the configuration of the Salvadora porphyry intrusion and the distribution of veins (Turneaure, 1960).**

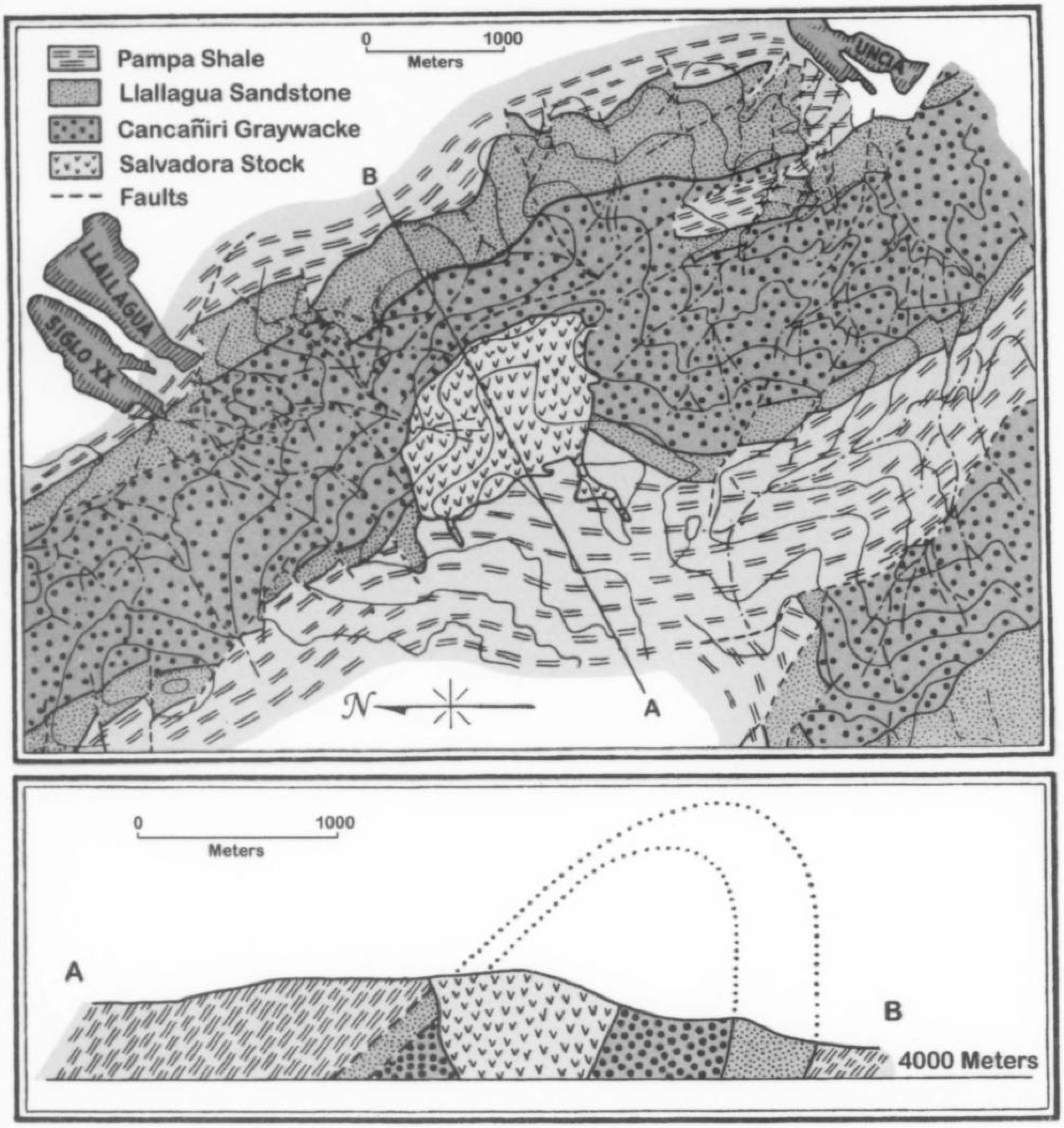


Figure 10. **Areal geology of the Llallagua Region surrounding the Salvadora porphyry stock (Deringer and Payne, 1937).**

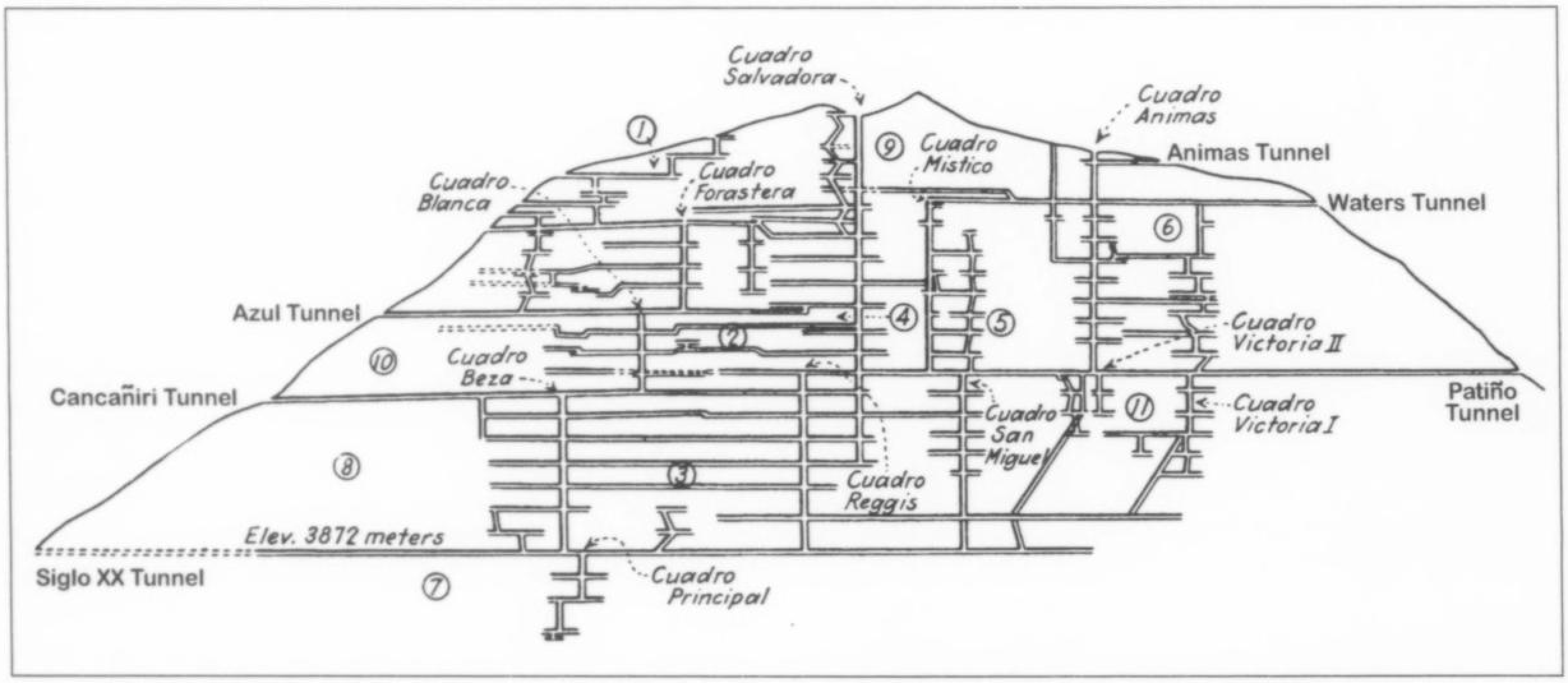


Figure 11. **Longitudinal cross-section through Salvadora Mountain showing some of the tunnels and mine sections (*cuadros*). The numbered sections are: (1) Azul Section, (2) Cancañiri Section, (3) Salvadora Section, (4) Laguna Section, (5) San Miguel Section, (6) Animas Section, (7) Siglo XX Section, (8) Ocho Section, (9) Nueve Section, (10) Diez Section, and (11) Patiño Tunnel Section (Deringer and Payne, 1937).**

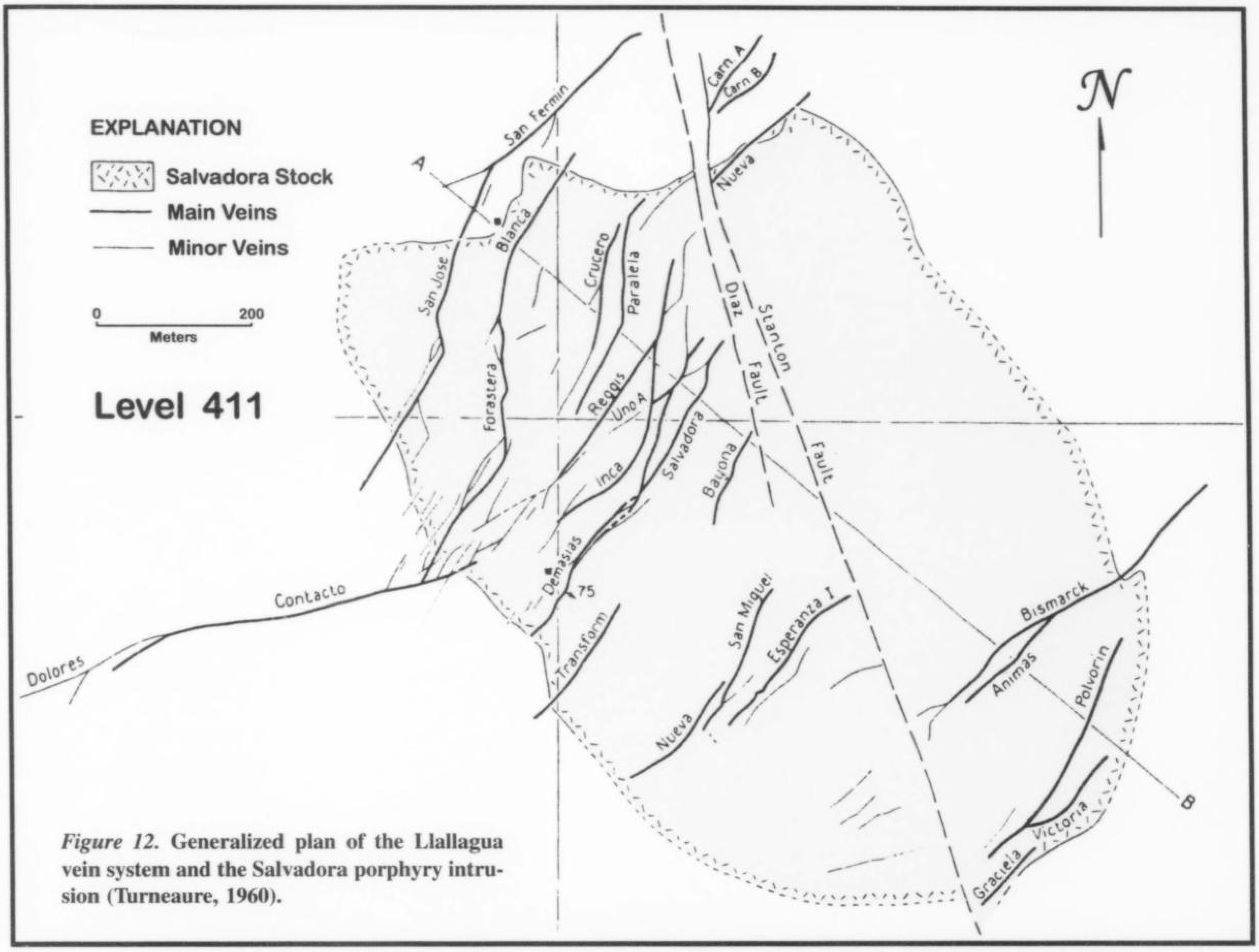


Figure 12. **Generalized plan of the Llallagua vein system and the Salvadora porphyry intrusion (Turneaure, 1960).**

Figure 13. **Mine train at the portal of the Siglo XX Tunnel, 1975. Rock Currier photo.**

In the second stage, pyrrhotite and franckeite were deposited, and in the next stage almost all pyrrhotite was replaced by pyrite, marcasite and siderite.

The various phosphates much beloved by collectors, most abundantly wavellite, were formed in the final stages of hydrothermal deposition, and were derived mostly from decomposition of primary fluorapatite. Greenockite and allophane were also deposited in this stage.

MINERALS

Allophane $Al_2SiO_5 \cdot H_2O$

Pearly white to capucine-orange mammillary masses of resinous, amorphous allophane form the matrix in some vauxite, vivianite and wavellite specimens. The allophane is unstable; unless kept under water it dehydrates to a chalky aggregate that gradually crumbles away, leaving thin crusts of blue vauxite with empty mammillary impressions on the bottom. More such specimens were found in 2001. A phosphate-rich variety containing about 8% P_2O_5 was described by Gordon (1944) as the mineral "phosphate allophane," but was discredited two years later as allophane. It also forms masses mixed with marcasite, pyrite and sphalerite.

Bandy (1944) noted that, although all transparent, pale, soft, opaline material found in the mine is placed under this heading, some is undoubtedly halloysite and some may be opal.

Alunite $KAl_3(SO_4)_2(OH)_6$

Gordon (1944) found rare white porcelaneous masses of alunite.

Andorite $PbAgSb_3S_6$

Gordon (1944) described andorite in small, brilliantly metallic, striated, prismatic steel-gray crystals to 1 mm, all covered by wavellite, with stannite and pyrite on quartz. Gordon identified 38 different crystal forms including five new ones. Andorite is quite rare in Llallagua, occurring only as small crystals in no way comparable to the much better crystals from Oruro, but it remains the only confirmed silver mineral in the central part of the Llallagua deposit.

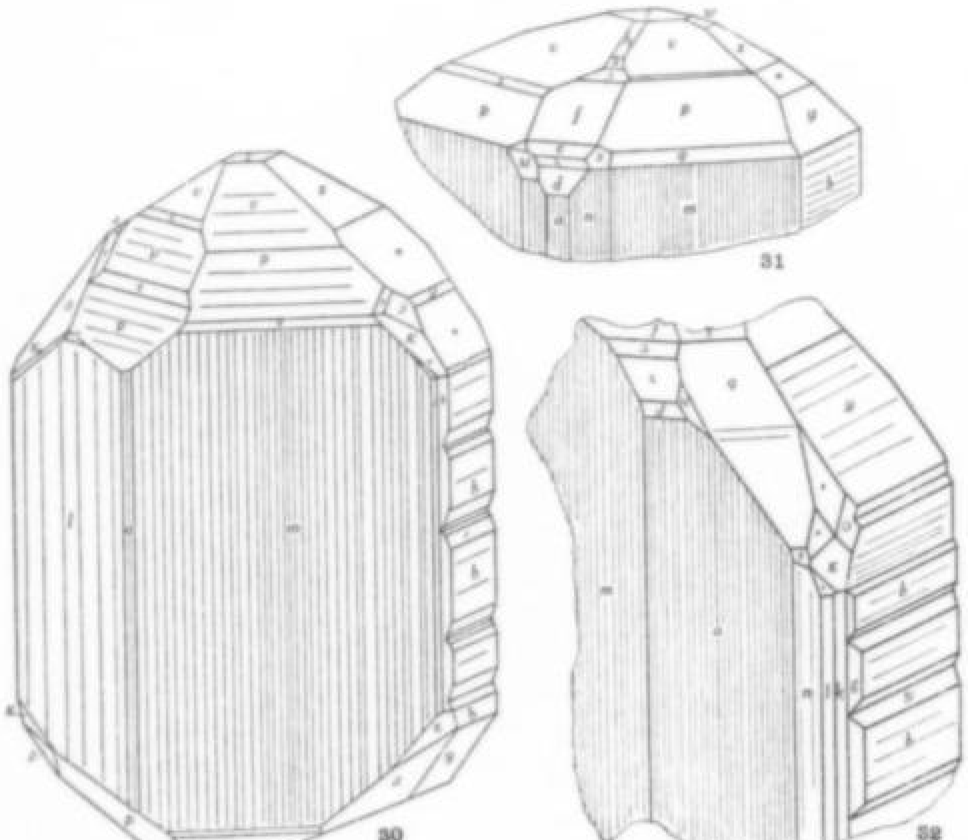


Figure 14. **Andorite from Llallagua; crystal drawings by Gordon (1944) showing 38 different crystal forms.**

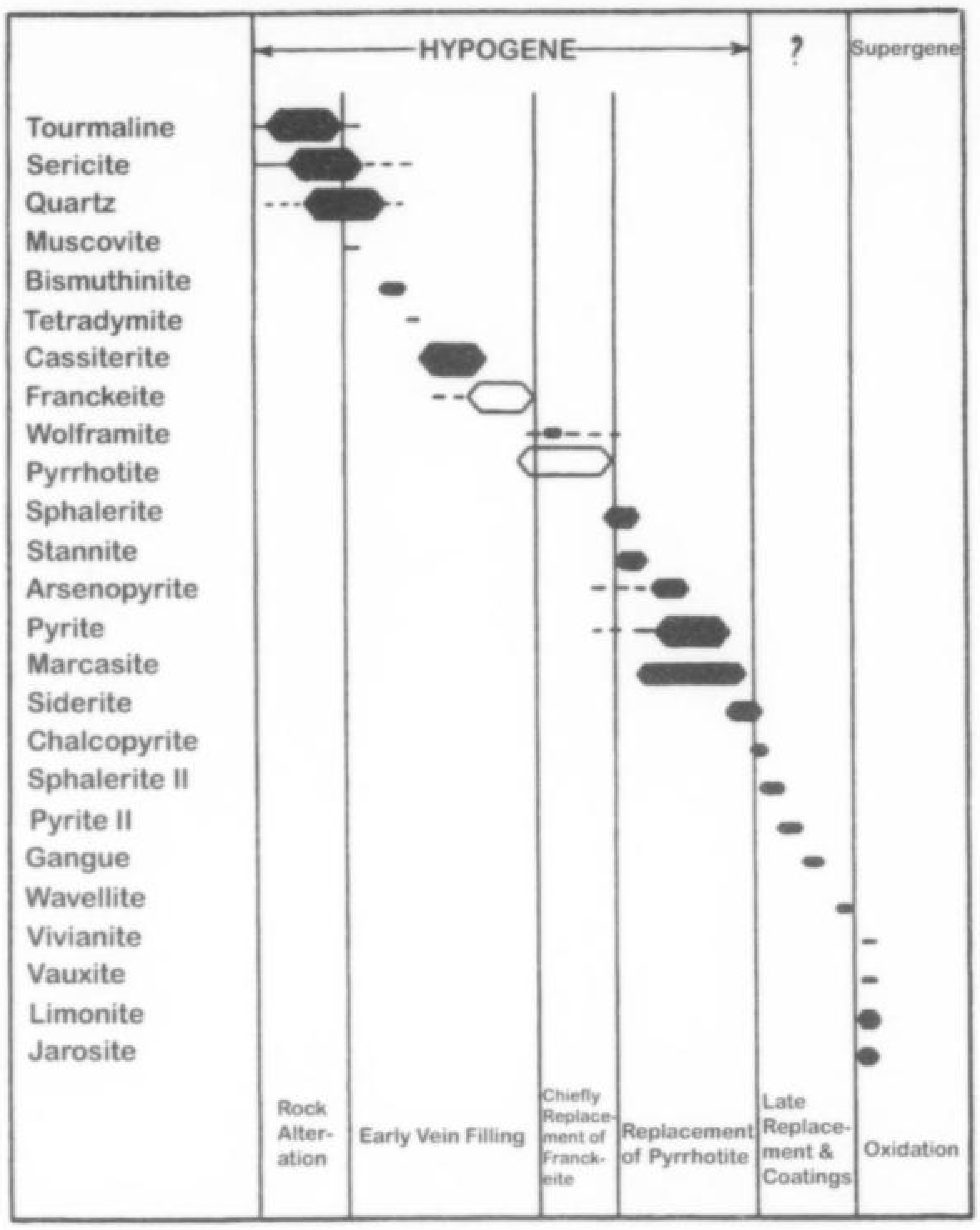


Figure 15. **Paragenetic sequence of crystallization as determined by Turneaure (1935).**

Anglesite $PbSO_4$

Bandy (1944) mentions a small vein composed of anglesite and quartz, 4 km northeast of the stock.

Antlerite $Cu_3(SO_4)(OH)_4$

Green acicular crystals of antlerite coating quartz were found on upper levels of the Salvadora vein (Bandy, 1944).

Arsenic As

On the Level 411 of the Demasias vein, a strange mass that looked like dark limonite was found to consist of alternating lamellae of native arsenic, realgar and gypsum (Davy, 1920). It appears to have formed through the oxidation of arsenopyrite.

Arsenopyrite FeAsS

Arsenopyrite has been found commonly in several veins, as well-formed twinned crystals, as sheaf-like groups of crystals up to 2 cm long, and as vuggy masses over a meter thick. It is widely distributed throughout the deposit, and is abundant in the Polvorin and Plata veins on the upper levels, although its presence tends to indicate low tin values. Fine specimens were found in the early 1940's on Level 275, and sheaf-like crystal clusters have been found along the Contacto vein on Level 355. "Magnificent specimens" of rounded and sheaf-like groups were found in 1941 in the Salvadora vein, above Level 215, and smaller crystals were collected along the San José vein below level 650 (Bandy, 1944). A vug in the footwall of the Contacto vein, on Level 250, yielded brilliant crystals of arsenopyrite, wolframite, jamesonite and bismuthinite perched on spongy quartz.

Augelite $Al_2(PO_4)(OH)_3$

Augelite was found by Bandy (1944) as small tabular crystals in the Bismarck vein.

***Table 1.* Minerals of the Siglo XX mine, Llallagua, Bolivia. Llallagua is the type locality for the species shown in bold. Species shown in *italics* are unconfirmed and therefore doubtful.**

Elements	
Arsenic	As
Bismuth	Bi
Copper	Cu
Silver	Ag
Sulfur	S
Sulfides and Sulfosalts	
Andorite	$PbAgSb_3S_6$
Arsenopyrite	$FeAsS$
Bismuthinite	Bi_2S_3
Bornite	Cu_5FeS_4
Boulangerite	$Pb_5Sb_4S_{11}$
Bournonite	$PbCuSbS_3$
Chalcocite	Cu_2S
Chalcopyrite	$CuFeS_2$
Covellite	CuS
Cylindrite	$(Pb,Sn)_8Sb_4Fe_2Sn_5S_{27}$
Franckeite	$Pb_6Sb_2FeSn_2S_{14}$
Galena	PbS
Greenockite	CdS
Jamesonite	$Pb_4FeSb_6S_{14}$
Marcasite	FeS_2
Miargyrite	$AgSbS_2$
Orpiment	As_2S_3
Potosíite	$Pb_6Sn_2^{4+}Fe^{2+}Sb_2^{5+}S_{16}$
Pyrargyrite	Ag_3SbS_3
Pyrite	FeS_2
Pyrrhotite	$Fe_{1-x}S$
Realgar	AsS
Sphalerite	ZnS
Stannite	Cu_2FeSnS_4
Stibnite	Sb_2S_3
Teallite	$PbSnS_2$
Tetrahedrite	Cu_3SbS_3
Tetradymite	Bi_2Te_2S
Troilite	FeS
Wurtzite	ZnS
Zinkenite	$Pb_9Sb_{22}S_{42}$
Chlorides, Fluorides	
Bismoclite	$BiOCl$
Oxides and Hydroxides	
Bismite	Bi_2O_3
Cassiterite	SnO_2
Cervantite	$\alpha\text{-}Sb^{3+}Sb^{5+}O_4$
Cronstedtite	$Fe_2^{2+}Fe^{3+}(Si,Fe^{3+})O_5(OH)_4$
Cuprite	Cu_2O
Goethite	$\alpha\text{-}Fe^{3+}O(OH)$
Hematite	Fe_2O_3
Jeanbandyite	$(Fe^{3+},Mn^{2+})(Sn^{4+})(OH)_6$
Natanite	$Fe^{2+}Sn^{4+}(OH)_6$
Rutile	TiO_2
Tenorite	CuO
Tungstite	$WO_3\cdot H_2O$
Wickmanite	$MnSn(OH)_6$
Carbonates	
Azurite	$Cu_3(CO_3)_2(OH)_2$
Bismutite	$Bi_2(CO_3)O_2$
Caledonite	$Pb_5Cu_2(CO_3)(SO_4)_3(OH)_6$
Malachite	$Cu_2(CO_3)(OH)_2$
Rhodochrosite	$MnCO_3$
Siderite	$FeCO_3$
Silicates	
Allophane	$Al_2SiO_5\cdot H_2O$
Chrysocolla	$(Cu,Al)_2H_2Si_2O_5(OH)_4\cdot nH_2O$
Cookeite	$LiAl_4(Si_3Al)O_{10}(OH)_8$
Cordierite	$Mg_2Al_4Si_5O_{18}$
Feldspar Group	
Hisingerite	$Fe_2Si_2O_5(OH)_4\cdot 2H_2O$
Kaolinite	$Al_2Si_2O_5(OH)_4$
Muscovite	$KAl_2AlSi_3O_{10}(OH)_2$
Nacrite	$Al_2Si_2O_5(OH)_4$
Opal	$SiO_2\cdot nH_2O$
Quartz	SiO_2
Thorite	$ThSiO_4$
Tourmaline Group	
Phosphates, Arsenates	
Augelite	$Al_2(PO_4)(OH)_3$
Chalcosiderite	$CuFe_6(PO_4)_4(OH)_8\cdot 4H_2O$
Childrenite	$FeAl(PO_4)(OH)_2\cdot H_2O$
Crandallite	$CaAl_3(PO_4)_2(OH,H_2O)_6$
Diadochite	$Fe_2(PO_4)(SO_4)(OH)\cdot 6H_2O$
Evansite	$Al_3(PO_4)(OH)_6\cdot 8H_2O$
Phosphates, Arsenates (continued)	
Faustite	$(Zn,Cu^{2+})Al_6(PO_4)_4(OH)_8\cdot 4H_2O$
Florencite-(Ce)	$CeAl_3(PO_4)_2(OH,H_2O)_6$
Fluorapatite	$Ca_5(PO_4)_3F$
Hagendorfite	$NaCaMn^{2+}(Fe^{2+},Fe^{3+},Mg)_2(PO_4)_3$
Hinsdalite	$(Pb,Sr)Al_3(PO_4)(SO_4)(OH)_6$
Mélonjosephite	$CaFe^{2+}Fe^{3+}(PO_4)_2(OH)$
Metavauxite	$FeAl_2(PO_4)_2(OH)_2\cdot 8H_2O$
Monazite	$(La,Ce,Y)PO_4$
Paravauxite	$FeAl_2(PO_4)_2(OH)_2\cdot 8H_2O$
Plumbo-gummite	$PbAl_3(PO_4)_2(OH,H_2O)_6$
Pyromorphite	$Pb_5(PO_4)_3Cl$
Rhabdo-phane-(La)?	$(La,Ce,Y)PO_4\cdot H_2O$
Sigloite	$FeAl_2(PO_4)_2(OH)_3\cdot 7H_2O$
Variscite	$AlPO_4\cdot 2H_2O$
Vauxite	$FeAl_2(PO_4)_2(OH)_2\cdot 6H_2O$
Vivianite	$Fe(PO_4)_2\cdot 2H_2O$
Wavellite	$Al_3(PO_4)_2(OH,F)_3\cdot 5H_2O$
Xenotime	YPO_4
Sulfates	
Alunite	$KAl_3(SO_4)_2(OH)_6$
Anglesite	$PbSO_4$
Antlerite	$Cu_3(SO_4)(OH)_4$
Barite	$BaSO_4$
Brochantite	$Cu_4^{2+}(SO_4)(OH)_6$
Caledonite	$Pb_5Cu_2(CO_3)(SO_4)_3(OH)_6$
Chalcanthite	$CuSO_4\cdot 7H_2O$
Creedite	$Ca_3Al_2(SO_4)(F,OH)_{10}\cdot 2H_2O$
Diadochite	$Fe_2(PO_4)(SO_4)(OH)\cdot 6H_2O$
Epsomite	$MgSO_4\cdot 7H_2O$
Gypsum	$CaSO_4\cdot 2H_2O$
Halotrichite	$FeAl_2(SO_4)_4\cdot 22H_2O$
Hinsdalite	$(Pb,Sr)Al_3(PO_4)(SO_4)(OH)_6$
Jarosite	$KFe_3(SO_4)_2(OH)_6$
Linarite	$PbCu(SO_4)(OH)_2$
Melanterite	$FeSO_4\cdot 7H_2O$
Pickeringite	$MgAl_2(SO_4)_4\cdot 22H_2O$
Römerite	$Fe^{2+}Fe_2^{3+}(SO_4)_4\cdot 14H_2O$
Tungstates	
Ferberite	$(Fe,Mn)WO_4$
Hübnerite	$(Mn,Fe)WO_4$
Scheelite	$CaWO_4$

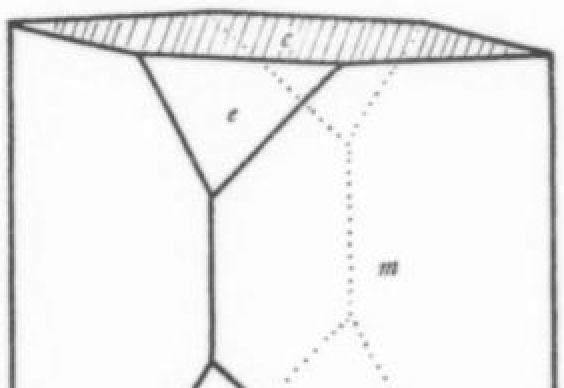


***Figure 16.* Arsenopyrite from Llallagua; crystal drawing by Gordon (1944).**

Azurite $Cu_3(CO_3)_2(OH)_2$

Gordon (1944) found tiny azurite crystals with malachite and covellite on weathered chalcopyrite.

Barite $BaSO_4$

Tabular barite crystals are associated with a recent hot spring deposit of tungsten-bearing psilomelane and opal at Uncia.

Bismite Bi_2O_3

Several products of the oxidation of bismuthinite have been found as earthy aggregates. Bandy (1944) lumps them together under bismite, but they need further study.

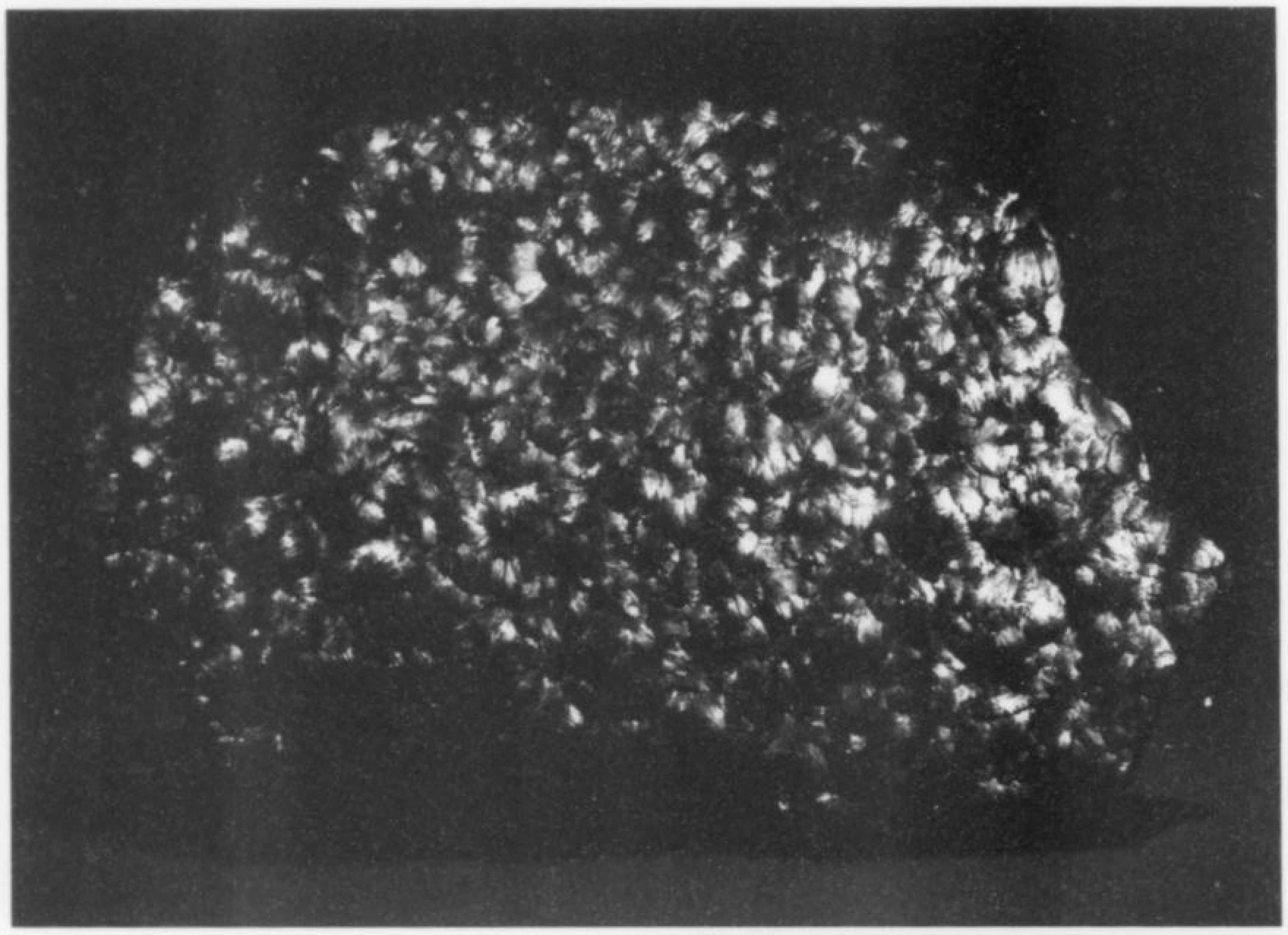


Figure 17. **Arsenopyrite crystal crust, 31 cm, from the Inca vein, Llallagua. Larry Reynolds photo; Bandy collection, now in the Natural History Museum of Los Angeles County.**

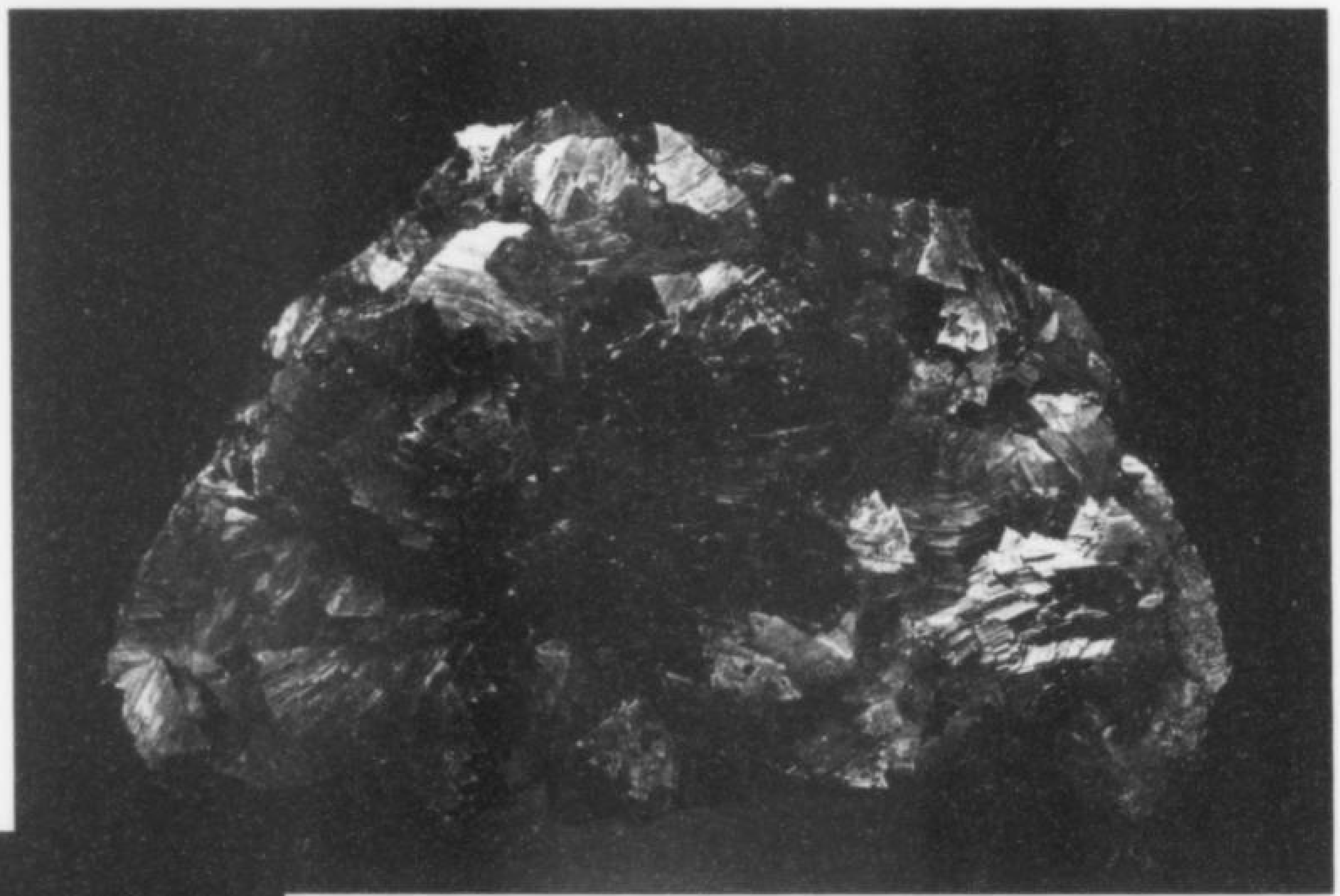
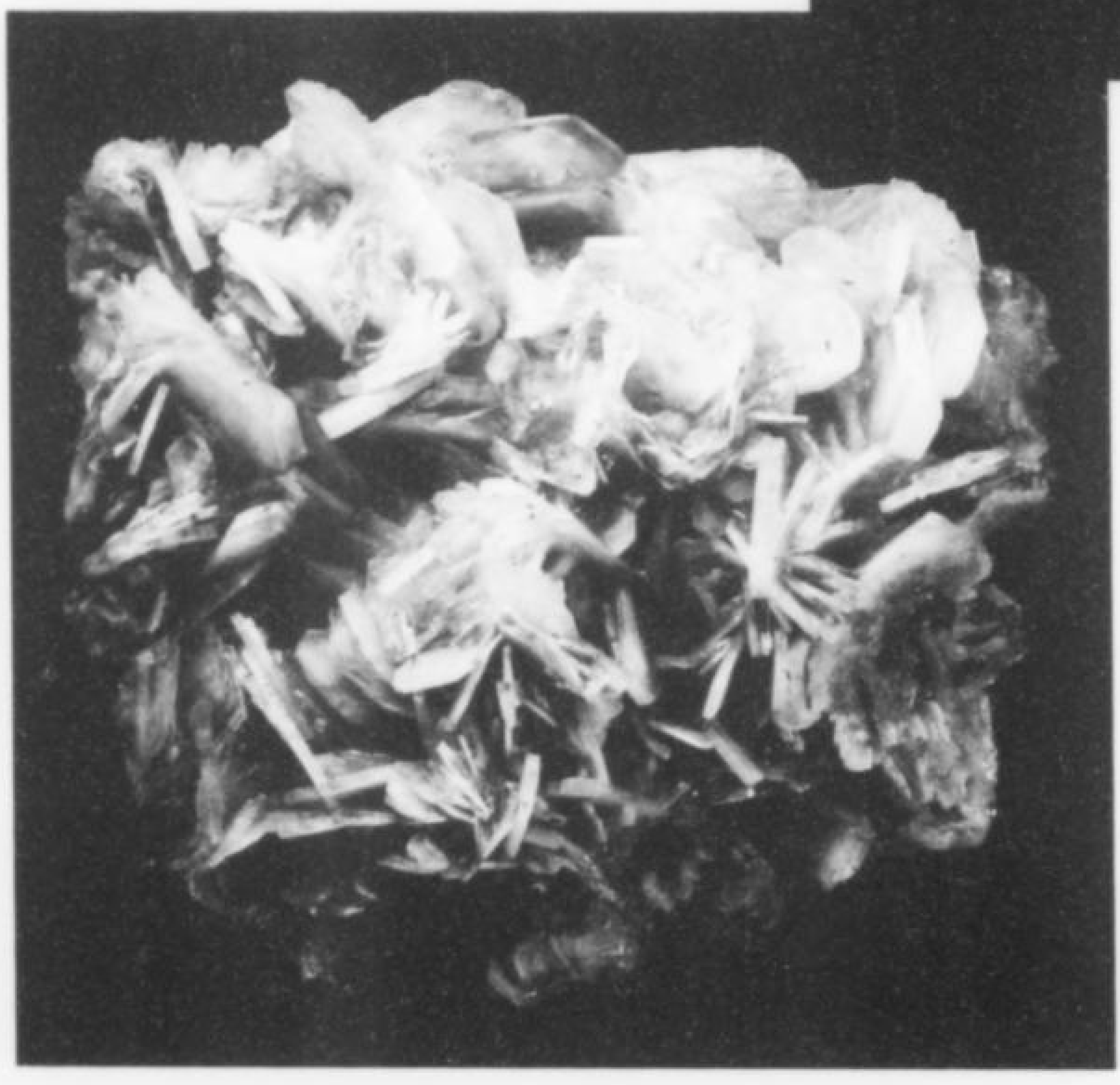


Figure 18. **Arsenopyrite crystal crust, 4.3 cm, from Llallagua. Les Wagner, Jr. collection; Jeff Scovil photo.**

Figure 19. **White barite crystal cluster, 4.7 cm, from the Luzmilla tunnel, Llallagua. Les Wagner, Jr. collection; Jeff Scovil photo.**



Bismoclite BiOCl

Bandy (1944) described pseudomorphs of massive micaceous bismoclite after bismuthinite with nice colorless crystals (!) of bismoclite to 2 mm in vugs. These came from below Level 411 of the Carnevalito vein.

Bismuth Bi

Native bismuth, younger than bismuthinite and ferberite, was occasionally found in the deeper levels. Ahlfeld and Muños Reyes (1955) mention scarce granular masses from Level 650 at the extreme northern end of the San José vein, where it was associated with bismuthinite, filling spaces between quartz crystals. The biggest cleavable bismuth masses found measured 10 cm across. Greene (1943) described pinkish native bismuth in association with cassiterite, bismuthinite, wolframite and quartz. An interesting lot of specimens came in the early 1990's from about Level 450 of the San José vein, where small masses of native bismuth associated with blue spherules of variscite were found.

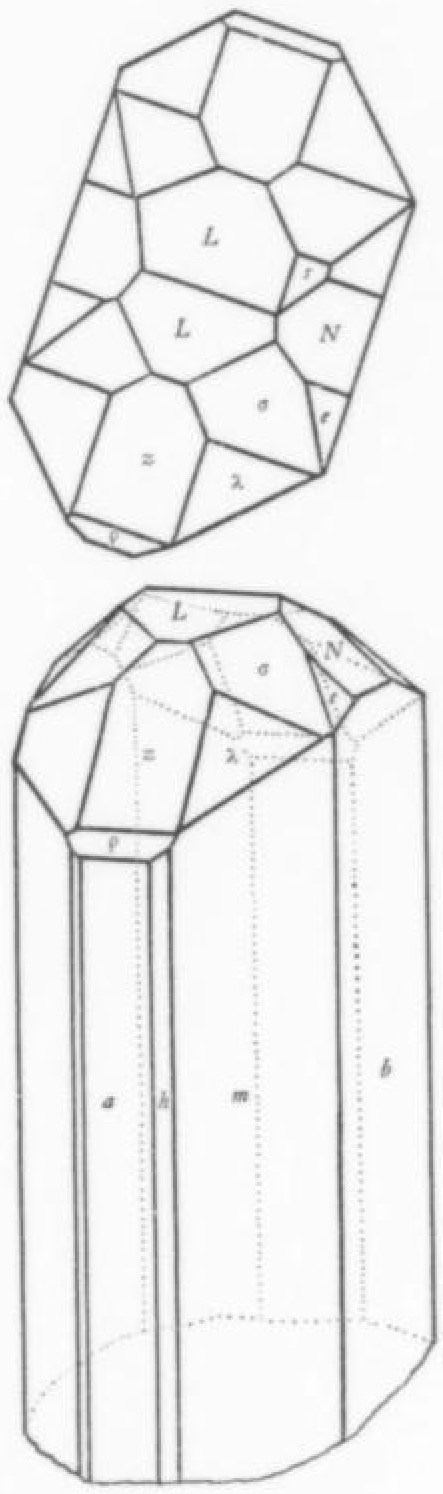


Figure 20. **Bismuthinite from Llallagua; crystal drawings by Gordon (1944).**

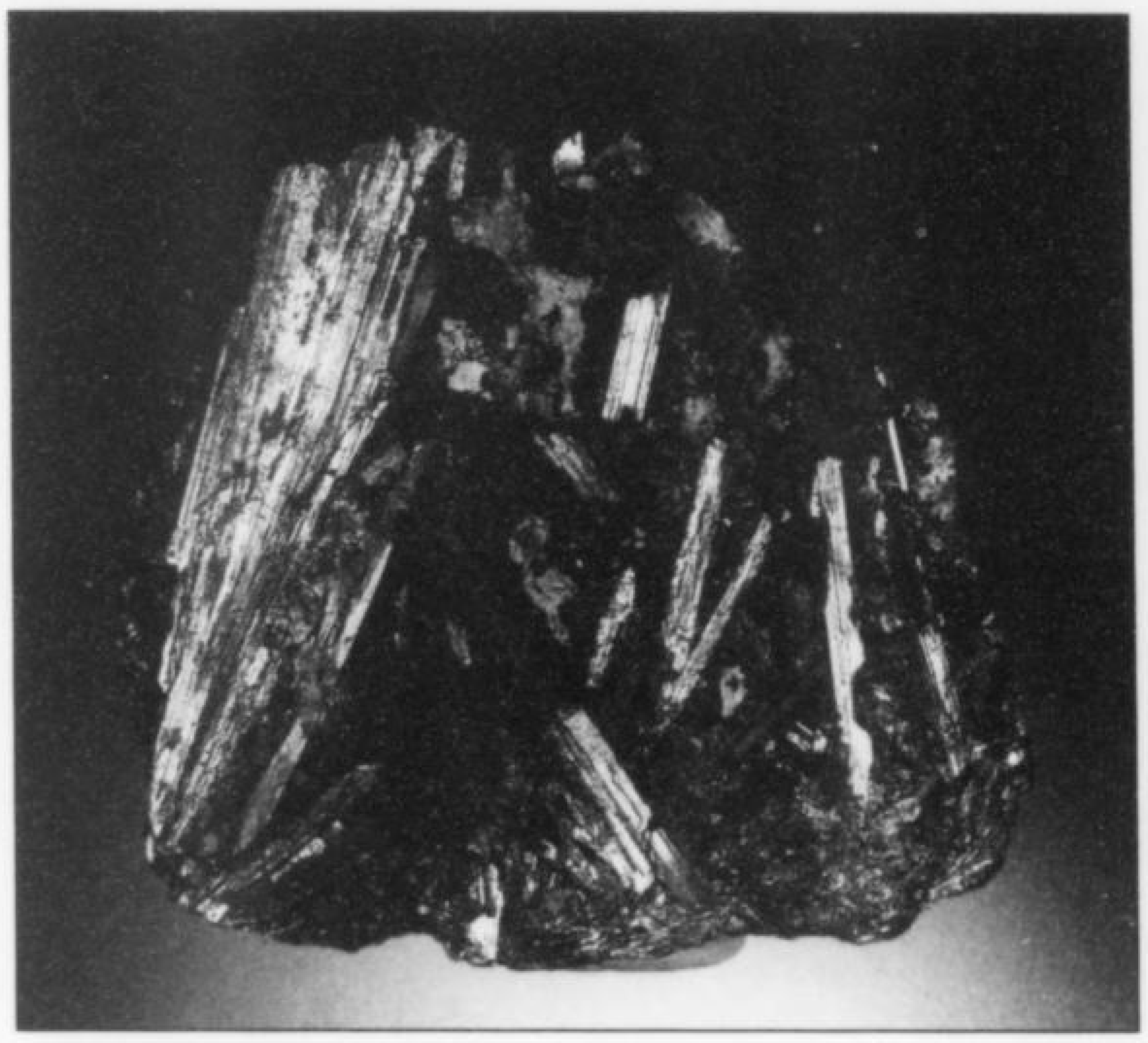


Figure 21. **Bismuthinite with cassiterite, 7 cm, from Llallagua, originally in Friedrich Ahlfeld's collection. Hyrsl collection and photo.**

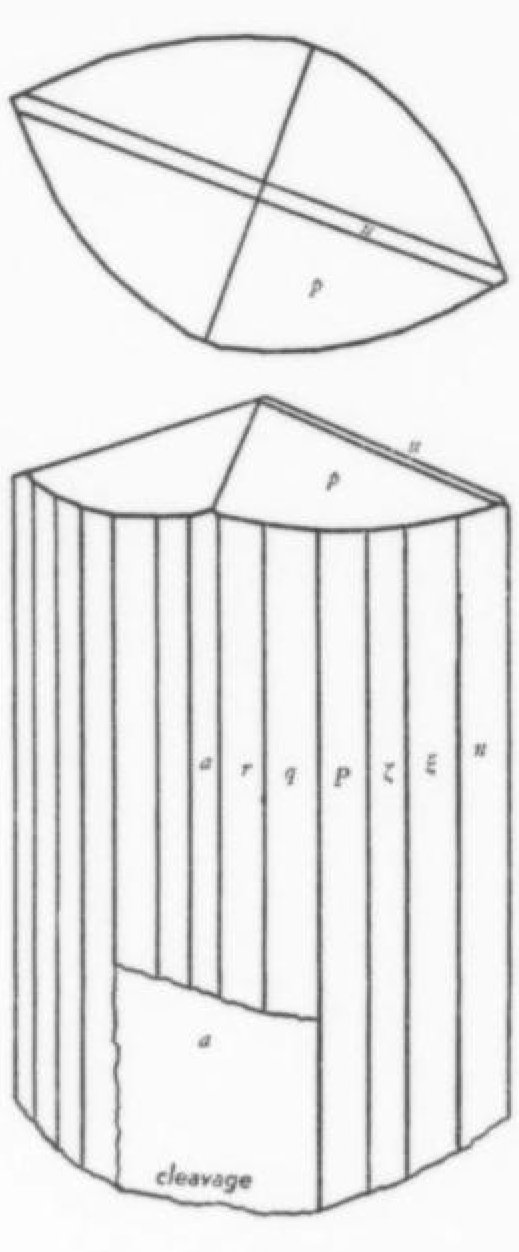


Figure 22. **Boulangerite from Llallagua; crystal drawings by Gordon (1944).**

Bismuthinite Bi_2S_3

Bismuthinite is one of the earliest formed minerals in the veins, and some of the largest known crystals of this species from anywhere in the world have been found at Llallagua. It forms lath-shaped crystals to 1 × 30 cm (Gordon, 1944) in vugs filled with iron sulfides or cassiterite, fluorapatite and wolframite. Free-standing terminated bismuthinite crystals to 1.6 cm can still be found rarely on the dumps. Massive bismuthinite, together with wolframite, is still produced in small amounts on the lower levels of the San José vein; there was significant commercial production from this vein between 1923 and 1925.

Bismutite $Bi_2(CO_3)O_2$

Bismutite has been reported from Llallagua by Petrov *et al.* (2001), on the basis of information on specimen labels.

Bornite Cu_5FeS_4

Bornite occurs as thin films on pyrite, as an alteration product of stannite (Ahlfeld and Muños Reyes, 1955).

Boulangerite $Pb_5Sb_4S_{11}$

Gordon (1944) measured a prismatic crystal from the Contacto vein that he concluded was boulangerite.

Bournonite $PbCuSbS_3$

Bandy (1944) mentioned small gray grains of bournonite.

Brochantite $Cu_4^{2+}(SO_4)(OH)_6$

Brochantite has been reported from Llallagua by Petrov *et al.* (2001), on the basis of information on specimen labels.

Caledonite $Pb_5Cu_2(CO_3)(SO_4)_3(OH)_6$

Bandy (1944) described crusts of caledonite and linarite near Level 355 of the Salvadora shaft.

Cassiterite SnO_2

Cassiterite is by far the most important ore mineral in Llallagua, commonly forming huge masses containing crystal-lined vugs. As of 1944, ore sufficient to yield more than 350,000 tons of tin had been produced. Ore shoots containing 40% to 50% cassiterite and measuring 2 meters across and 30 meters in length were mined on the San José/San Firmin vein, and blocks of nearly pure cassiterite 2 meters across have been recovered (Gordon, 1944).

Although cassiterite specimens from Llallagua never attain the size and beauty of the best specimens from the Viloco mine in La Paz department, they can be quite attractive. The most common type of Llallagua cassiterite specimens shows black twinned

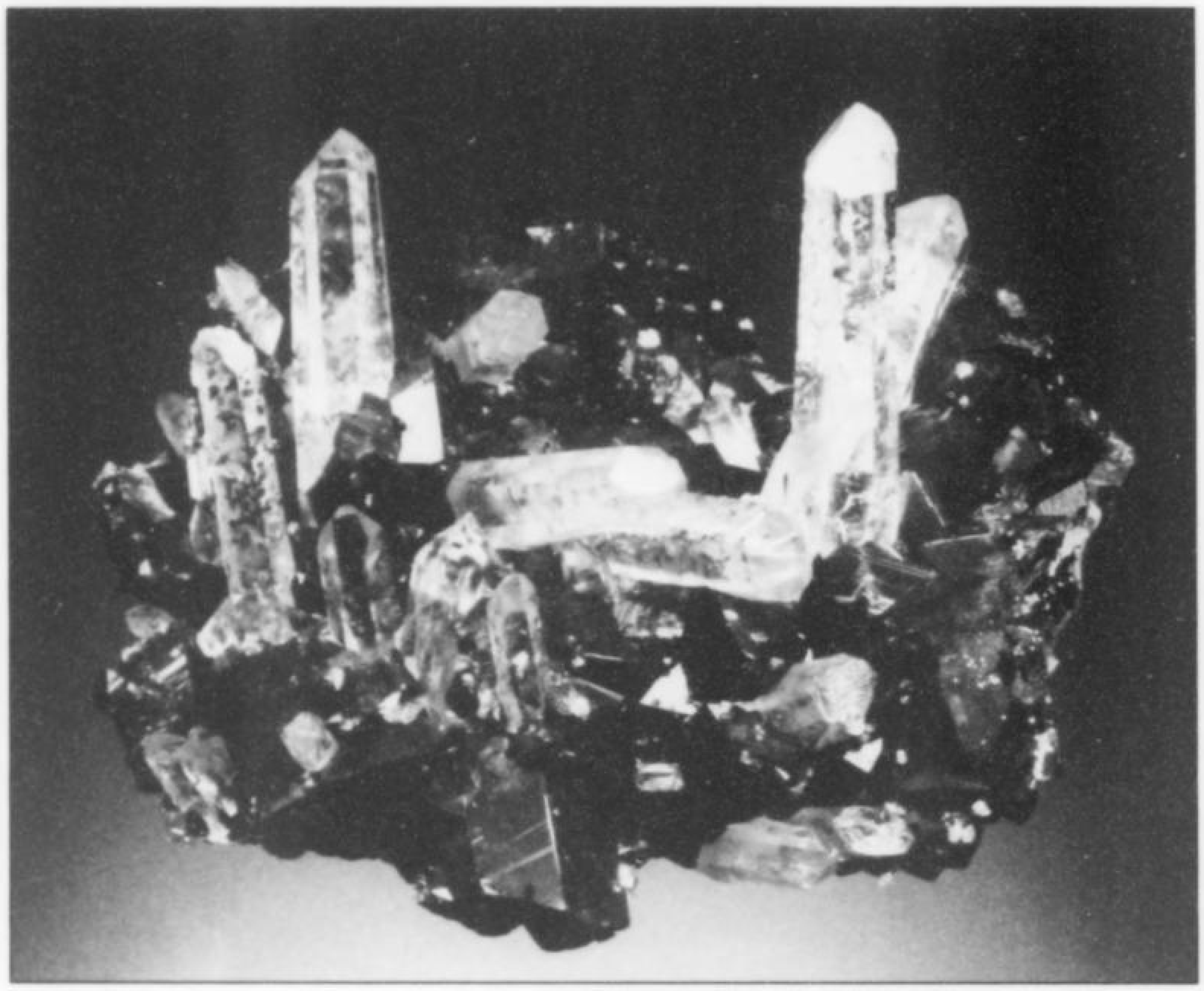


Figure 23. **Cassiterite and quartz, 3.5 cm, from Llallagua. Seaman Mineral Museum collection, Michigan Technological University; George Robinson photo.**

Figure 24. **Cyclic twin of cassiterite, 8 mm, from Llallagua. Seaman Mineral Museum collection, Michigan Technological University; John Jaszczak photo.**

crystals to 1 cm, in most cases on quartz but also on tourmaline, pyrite or monazite. Cassiterite is frequently found coated with drusy wavellite.

Bandy (1944) classified Llallagua cassiterite habits into three of the types established by Ahlfeld (1955): Types II, III and V. Type II is represented by the black to dark brown, color-zoned crystals and massive ore that are the most common. The largest crystals, with faces up to 1 cm, are from the Salvadora vein, and somewhat smaller crystals have come from the San José/San Firmin veins. Type II crystals are contact-twinned on (011) (the Zinnwald Law), and repeated twinning commonly results in cyclic twins. The faces tend to be irregular and striated.

The rare Type III crystals, simple combinations of prism and dipyramid, are small and unzoned; they range from colorless to pale yellow and brown. Doubly terminated crystals are common, but the size rarely exceeds 3 mm. Good specimens have come from the upper portions of the Contacto vein, especially on Level 295 (associated with stannite) and along the rim of the Animas Branch M above Level 250. Some clusters show a marked tendency toward parallel growth, and often coat breccia fragments in fault zones (Gordon, 1944). Attractive honey-yellow crystals were found in the Inca vein above Level 180.

Type V cassiterite is cryptocrystalline with a colloidal texture, botryoidal form and radially fibrous structure—what is comonly referred to as "wood tin." Good specimens have been found in the Contacto vein above Level 250, and along a branch of the Salvadora vein near Level 180. Greene (1943) mentions rare cassiterite stalactites to 4 cm long.

Most attributions of "wood tin" specimens to Llallagua are erroneous; this material is found much more abundantly on a volcanic plateau in the Macha area, about 80 km southeast of Llallagua.

On the vast dumps of volcanic waste in Llallagua it is still easy to find vugs with tiny translucent dark brown cassiterite crystals associated with quartz and tourmaline.

Cervantite α-$Sb^{3+}Sb^{5+}O_4$

Several products of the oxidation of stibnite and jamesonite have been found as earthy aggregates. Bandy (1944) mentions them together under cervantite, but the specimens will require further study for accurate characterization.

Chalcanthite $CuSO_4 \cdot 7H_2O$

Masses of beautiful blue crystals of post-mining chalcanthite are found in several sections of the mine, especially along the San José vein, growing in fissures in the rock walls or hanging from wooden beams, and these are popular with local mineral collectors, although many of their specimens of *calcantita* are really the more common cuprian melanterite.

Chalcocite Cu_2S

Chalcocite has been described as an alteration product of stannite (Ahlfeld and Muños Reyes, 1955). It is more abundant in the southern part of the mine.

Chalcopyrite $CuFeS_2$

Chalcopyrite occurs very rarely with supergene Cu sulfides, and as microscopic inclusions in sphalerite.

Figure 25. **Chalcosiderite spherules on quartz crystals, 2 cm (as shown), from Llallagua. Hyrsl collection and photo.**

Chalcosiderite $CuFe_6(PO_4)_4(OH)_8 \cdot 4H_2O$

Blue spheres of chalcosiderite up to 2 mm in diameter occur in quartz cavities, accompanied by small vivianite crystals.

Figure 26. **Black childrenite on matrix, 4 cm, from Llallagua. Hyrsl collection and photo.**

Childrenite $FeAl(PO_4)(OH)_2 \cdot H_2O$

Childrenite has been found as druses of pale brown to dark brown, millimeter-size tabular crystals in parallel growth coating fissure surfaces to a half-meter square (Bandy, 1944), and as rosettes of translucent, yellow-orange to zinc-orange tabular crystals encrusting paravauxite (Gordon, 1944). The crystal size is typically up to about 1 mm, though rare crystals to 3 mm have been collected. Bandy (1944) reports it from the Contacto vein, the southern end of a branch of the Serrano vein, and on the San José vein from Level 355 to Level 516. Although it is often found in relative abundance without associated species, it is usually found coating paravauxite or wavellite. Loose aggregates of childrenite filling vugs have been found in the hanging wall of the Contacto vein (Bandy, 1944).

More recently childrenite has been found as very dark brown, radiating spheres up to about 3 mm in diameter, many with whitish centers; some of the spheres perch on vivianite. The authors' chemical analysis showed Fe strongly prevailing over Mn, in both the brown and white portions, suggesting that there is no eosphorite at Llallagua. Local Bolivian dealers are selling specimens of this material erroneously labeled "sigloita," and the misidentification has been uncritically perpetuated by some foreign dealers; *caveat emptor*!

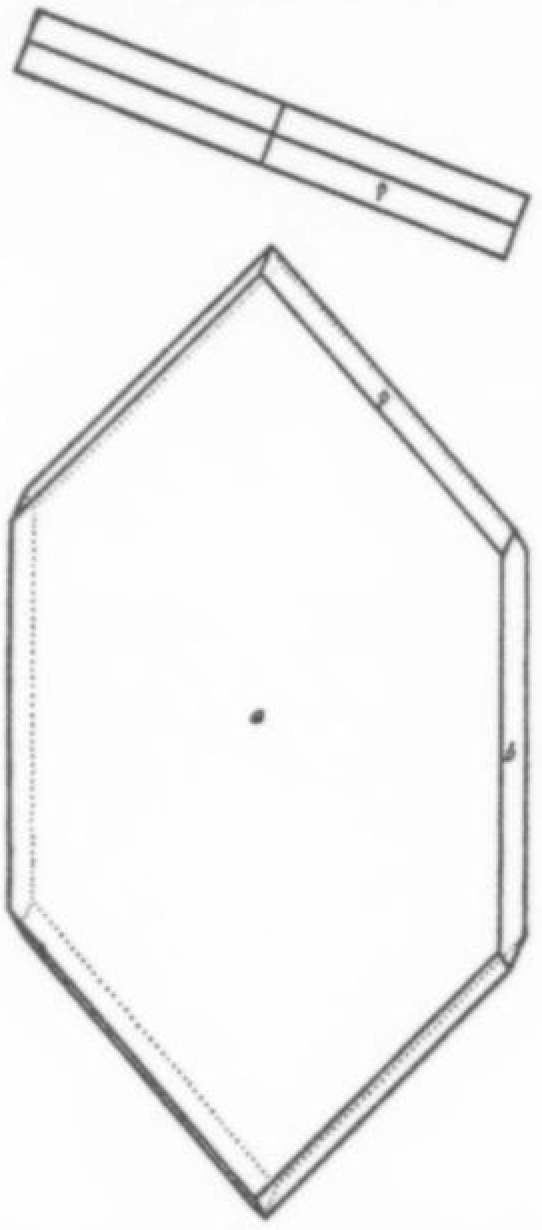


Figure 27. **Childrenite from Llallagua; crystal drawings by Gordon (1944).**

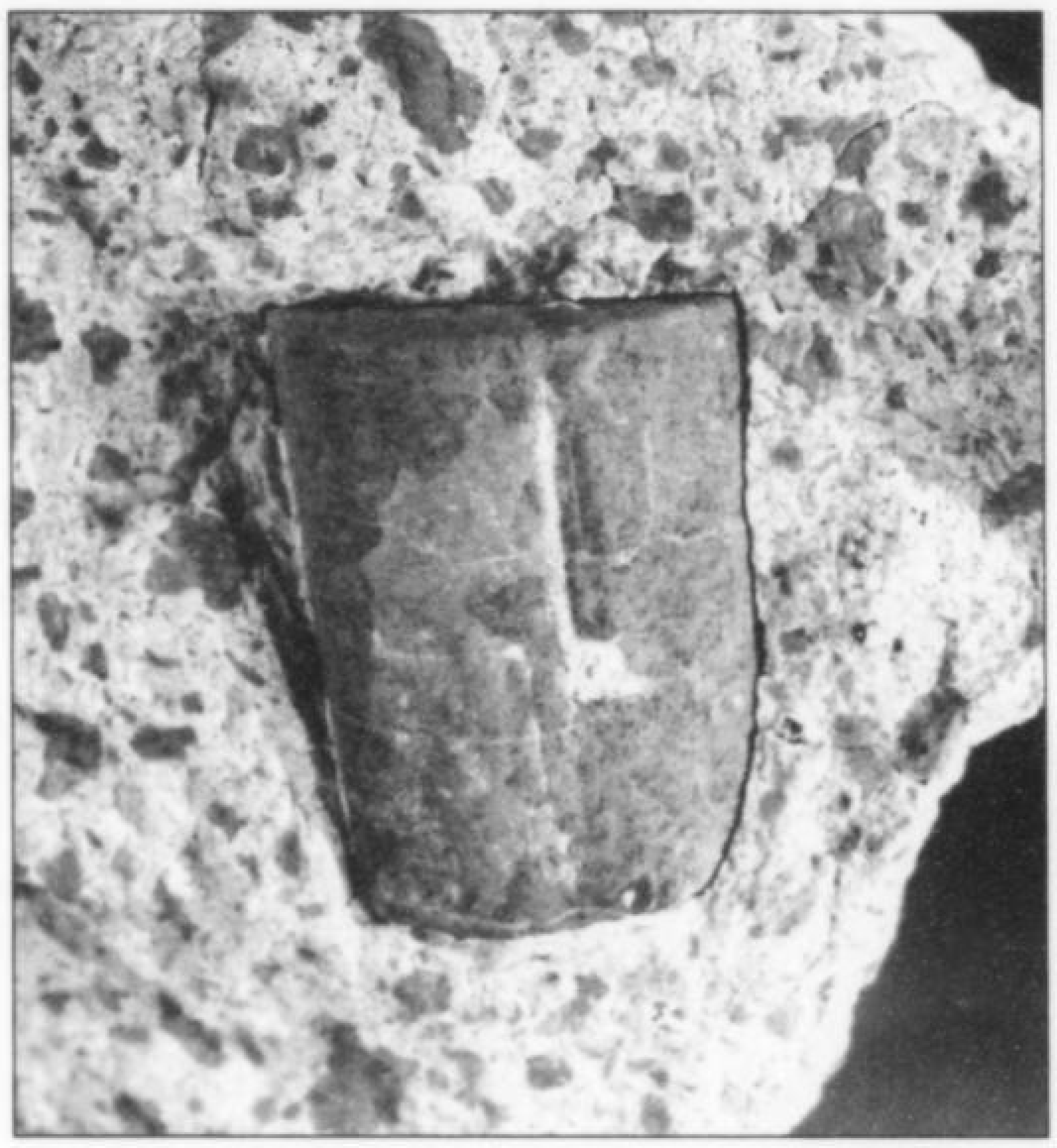


Figure 28. **Cordierite crystal, 1.8 cm, from the Bismarck vein, Level 500. Bandy collection, now in the Natural History Museum of Los Angeles County; Anthony Kampf photo.**

Chrysocolla $(Cu,Al)_2H_2Si_2O_5(OH)_4 \cdot nH_2O$

Chrysocolla occurs sporadically as a decomposition product, perhaps of post-mining origin. Pale blue crusts can be seen in the vertical north wall of one of the collapse craters caused by block caving.

Cookeite $LiAl_4(Si_3Al)O_{10}(OH)_8$

Very surprising was a single find of cookeite as pearly cream-colored scales in milky quartz, together with bismuthinite needles (Gordon, 1944).

Copper Cu

Native copper has been found in several places just below the oxidation zone in stannite-bearing veins, very rarely as tiny crystals to 1 mm.

Cordierite $Mg_2Al_4Si_5O_{18}$

Bandy (1944) found perfect, simple prismatic crystals of cordierite, largely altered to gray masses of *pinita*, reaching 2 cm long and 1 cm thick, in quartz porphyry dikes cutting the breccia in the volcanic stock. The cordierite probably originated by assimilation of slates into the magma. Grains of blue to violet, unaltered cordierite occur in the country rock tuff near Catavi.

Covellite CuS

Covellite is seen commonly as thin films with chalcocite, both species having weathered from stannite.

Crandallite $CaAl_3(PO_4)_2(OH,H_2O)_6$

Crandallite is common in a mixture with variscite as part of agate-like phosphate concretions. Brownish pink botryoidal micro-aggregates are also seen on some recent vauxite specimens.

Creedite $Ca_3Al_2(SO_4)(F,OH)_{10} \cdot 2H_2O$

Creedite has been reported from Llallagua by Petrov *et al.* (2001), on the basis of information on specimen labels. However, the authors believe that the specimens in question are probably mislabeled as to locality, and confirmation of the source is lacking. Therefore the occurrence at Llallagua must be considered doubtful.

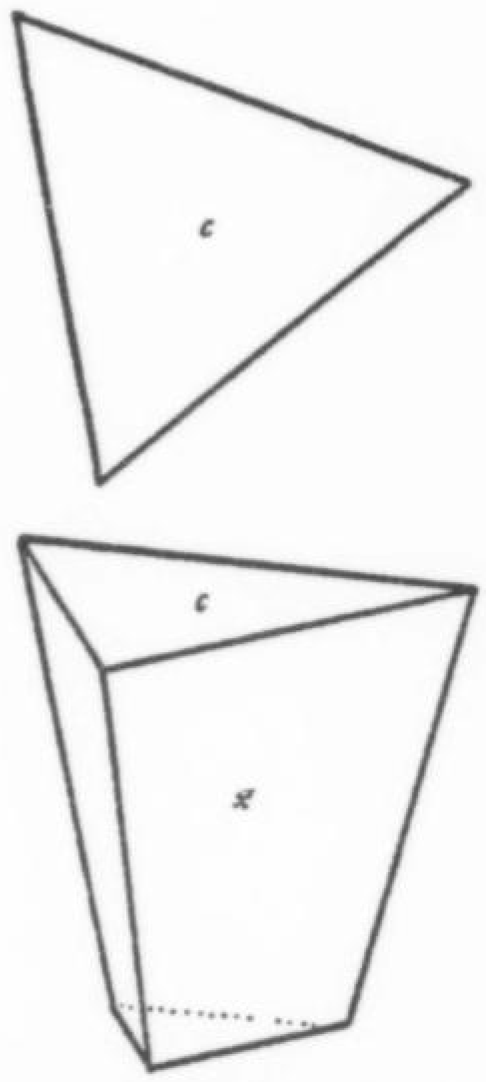


Figure 29. **Cronstedtite from Llallagua; crystal drawings by Gordon (1944).**

Cronstedtite $Fe^{2+}_2Fe^{3+}(Si,Fe^{3+})O_5(OH)_4$

Black crystals of cronstedtite with triangular cross-section, displaying only {$20\bar{2}1$} and {0001} faces, as well as compact masses of cronstedtite, were once found on hisingerite, marcasite, pyrite, siderite and rhodochrosite. According to Bandy (1944), the best crystals came from Level 411 and Level 516 of the Contacto vein. Also, cronstedtite is abundantly present on recent vivianite specimens, as olive-green mammillary crusts associated with pyrite and sphalerite.

Cuprite Cu_2O

Small masses of cuprite have been found with native copper in the Inca and San José veins.

Cylindrite $(Pb,Sn)_8Sb_4Fe_2Sn_5S_{27}$

Cylindrite occurs in a unique habit consisting of very thin, lead-gray folia rolled up into cylinders. Its occurrence is limited to deposits between Oruro and Chorolque in Bolivia; specimens from the type locality of Poopó are better known, but the occurrence at Llallagua is unusual in that, instead of being solidly intergrown in masses, the cylinders (up to 1 cm long) have grown free, projecting into vugs and having one "termination" exposed. Cylindrite crystals like these, always accompanied by franckeite, are still occasionally found in recently produced, vuggy franckeite ore. The best known cylindrite specimen from Llallagua, showing cylindrite crystals on stannite, is in the Bandy Collection, Natural History Museum of Los Angeles County.

Diadochite $Fe_2(PO_4)(SO_4)(OH)\cdot 6H_2O$

Vitreous stalactitic masses of diadochite of colloidal origin were once found on Level 320 of the Contacto vein, and large masses have been found in other stoped-out tin veins. Bandy (1944) reported that coffee-brown diadochite formed in great abundance on the floors of old workings below Level 650, and formed layers to 60 cm deep in parts of Level 720 after it had been flooded for over ten years. Some diadochite masses were plastic when first found, but dehydrated rapidly outside the mine, crumbling into pieces smaller than 1 cm.

Epsomite $MgSO_4\cdot 7H_2O$

White epsomite fibers occur on melanterite and chalcanthite stalactites.

Evansite $Al_3(PO_4)(OH)_6\cdot 8H_2O$

Pale orange, transparent, resinous masses of evansite, much resembling tree resin, are occasionally found in association with metavauxite.

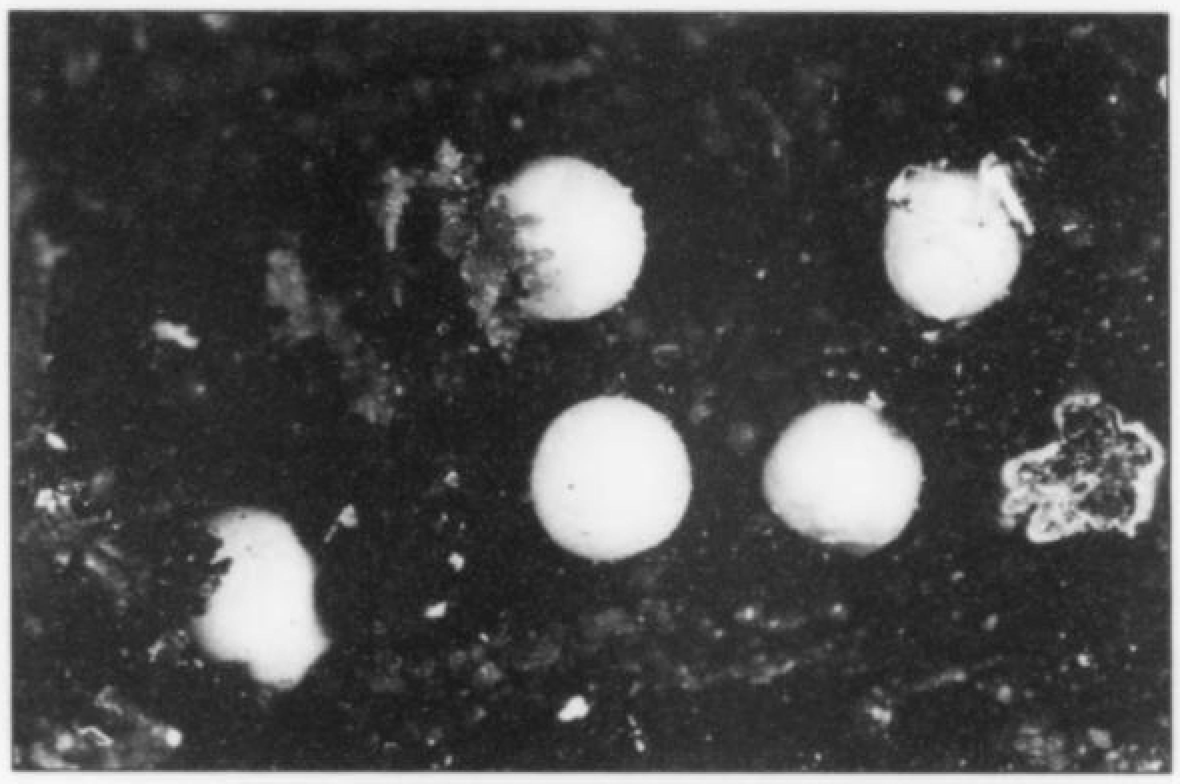


***Figure 30.* White faustite spherules to 0.4 mm, from Llallagua. Seaman Mineral Museum collection, Michigan Technological University; John Jaszczak photo.**

Faustite $(Zn,Cu^{2+})Al_6(PO_4)_4(OH)_8\cdot 4H_2O$

Faustite is known on a single specimen from the Siglo XX mine in the collection of the A. E. Seaman Mineral Museum, Michigan Technological University (G. Robinson, personal communication, 2005). The specimen, which was collected in the early 1940's by Reynolds M. Denning, consists of a 3-cm marcasite pseudomorph after pyrrhotite intergrown with quartz, the surface of which is encrusted with microcrystals of colorless wavellite, pinkish sphalerite, orange greenockite and sparse, porcelaneous, white spheres of faustite. Identification of the faustite was made by X-ray diffraction and confirmed by energy dispersion X-ray spectroscopy, which showed minor concentrations of Fe and Cd in addition to the major elements Zn, Cu, Al and P.

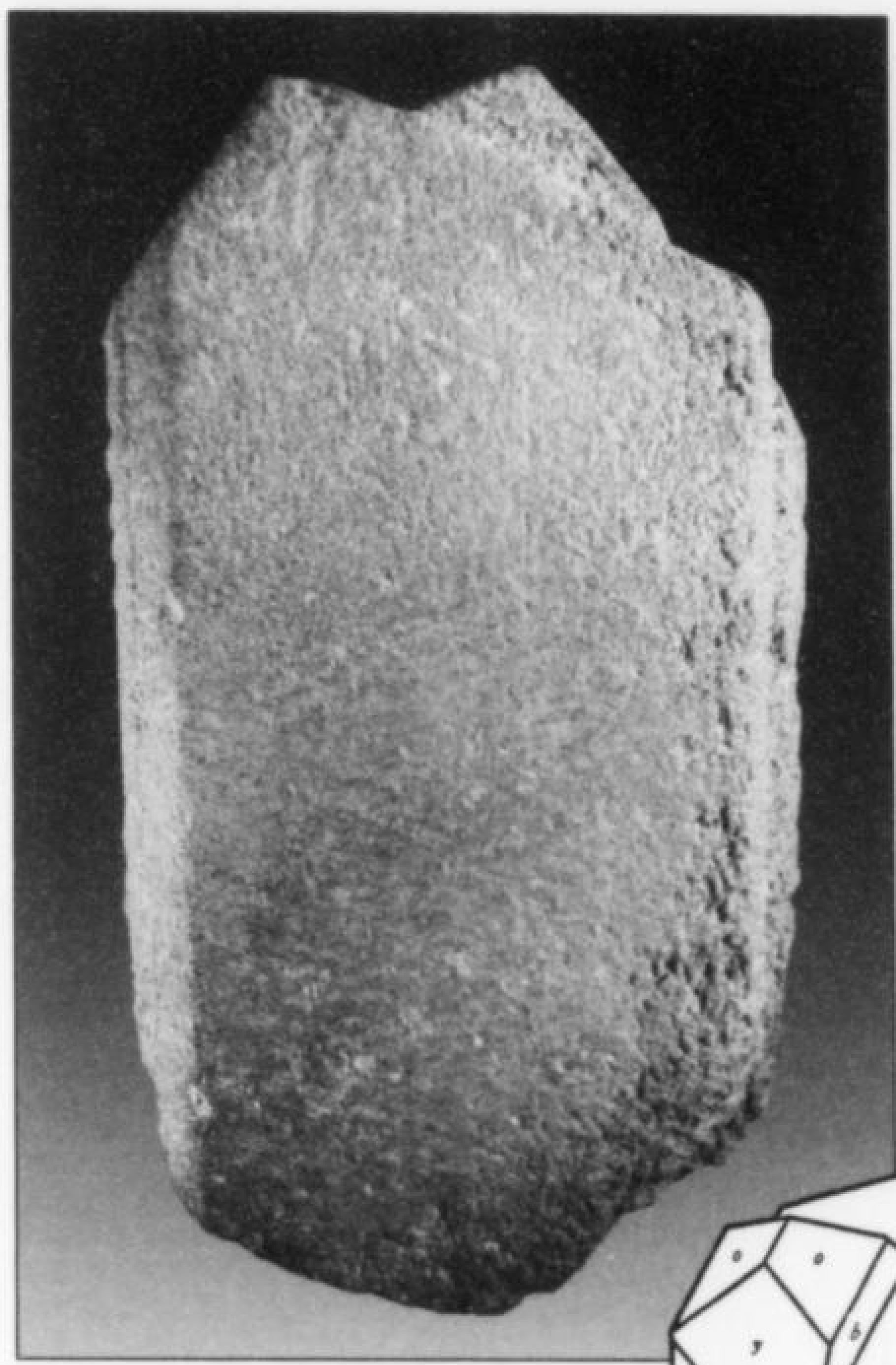


***Figure 31.* Orthoclase twin (probably a pseudomorph), 3 cm, from Llallagua. Bandy collection, now in the Natural History Museum of Los Angeles County; Anthony Kampf photo.**

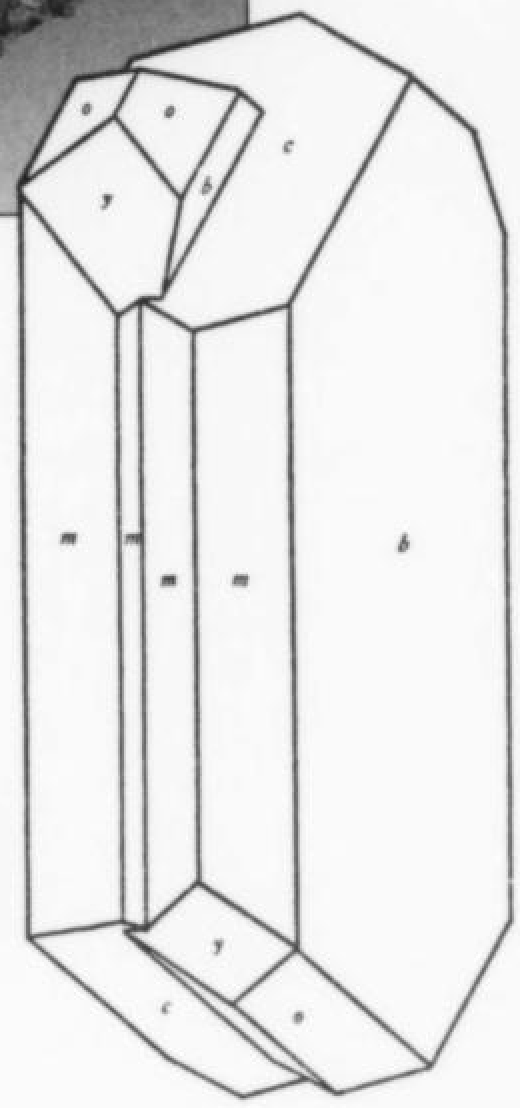


***Figure 32.* Orthoclase twin from Llallagua; crystal drawing by Gordon (1944).**

Feldspar Group

Unaltered crystals of orthoclase and plagioclase (probably oligoclase), including Carlsbad-law twins, have been found rarely as phenocrysts in the volcanic porphyry. Almost all Carlsbad-twinned crystals of feldspar (both orthoclase and plagioclase) have been replaced by mixtures of younger minerals, e.g. tourmaline, sericite (= fine-grained muscovite), quartz, kaolinite, and rarely cassiterite or pyrite (Hyrsl and Petrov, 1998). These pseudomorphs can reach up to about 8 cm.

Ferberite $(Fe,Mn)WO_4$

"Wolframite" (mostly ferberite) was once an important Llallagua ore mineral, commercially produced as tungsten ore during World War I, but good crystals are much less common than from other Bolivian mines such as Tazna.

Ferberite occurs at Llallagua in opaque to translucent, black to reddish brown crystals up to 5 cm or more, showing the characteristic perfect cleavage parallel to (010). The crystals are usually

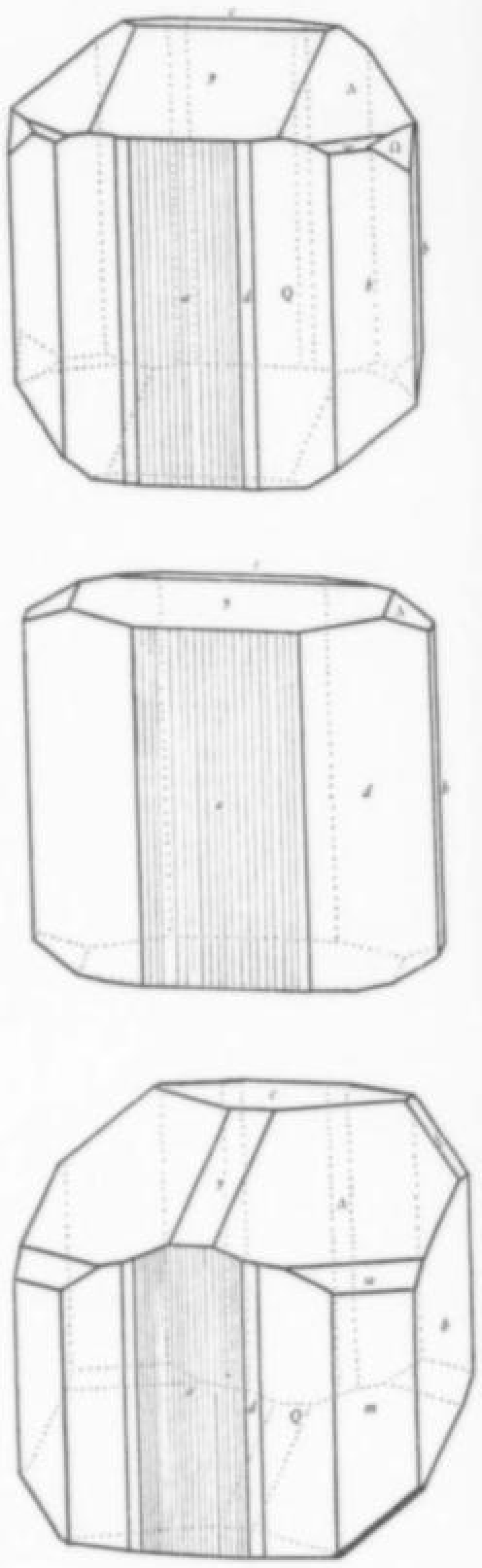


Figure 33. **Ferberite from Llallagua; crystal drawings by Gordon (1944).**

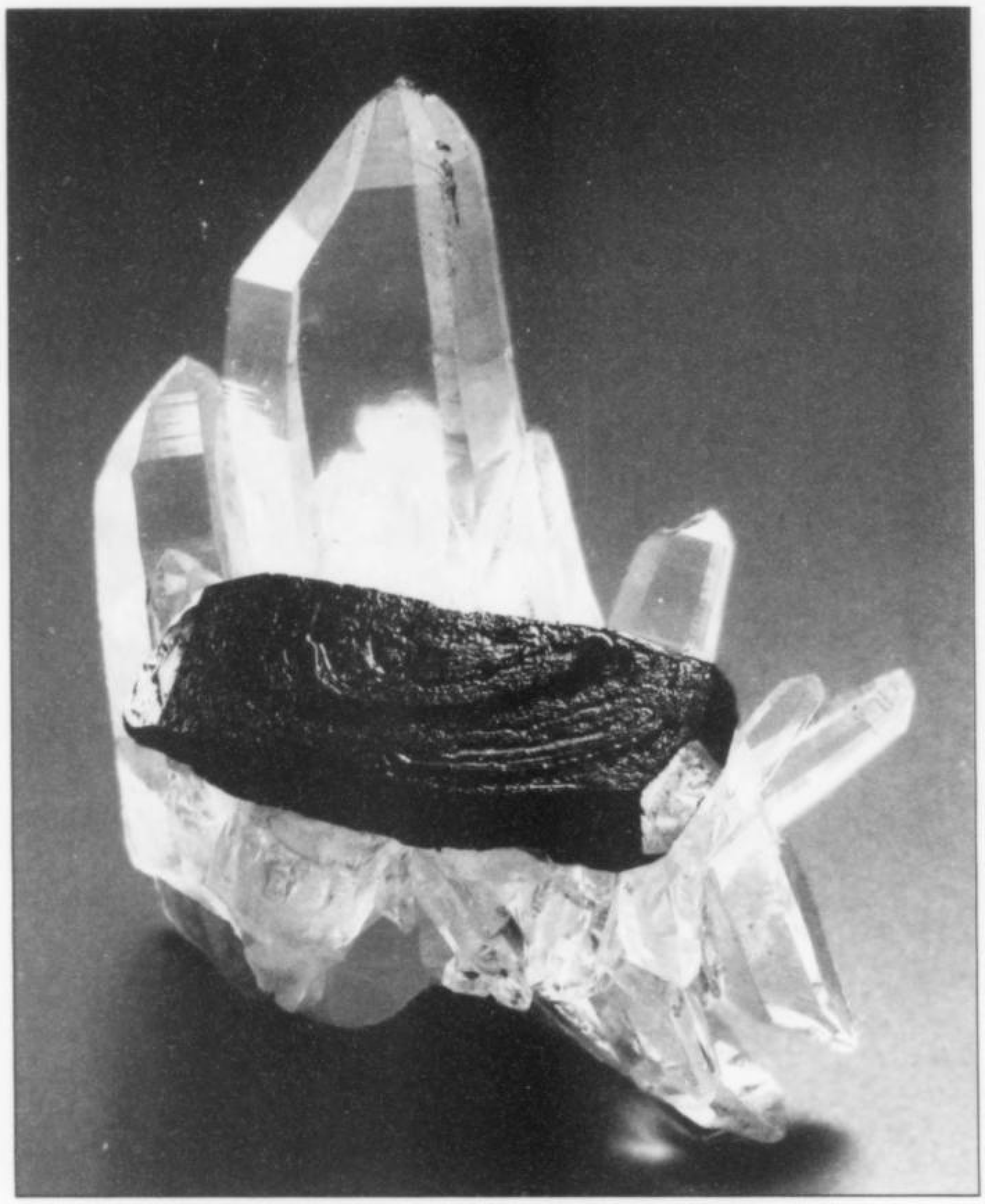


Figure 34. **Ferberite crystal on quartz, 7.4 cm, said to be from Llallagua, though more likely from Amutara. William Larson collection; Wimon Manorotkul photo.**

tabular on (100), but may also be elongated parallel to [100]. Microcrystals, on the other hand, tend to be prismatic/bladed and elongated parallel to [001]. Twinning is common, usually about [001], and "fish-tail" to triangular twins are also known, from the San José, San Fermin, Salvadora, Paralela and Blanca veins. Fine tabular crystals have also been found in quartz-lined vugs in the Salvadora, Bismarck, Contacto and San Miguel veins (Bandy, 1944). The larger crystals occur on cassiterite and bismuthinite, and are sometimes found in columnar aggregates. Small, black acicular crystals in radial aggregates have been found on quartz crystals with secondary bismuthinite crystals (Gordon, 1944).

Florencite-(Ce) $CeAl_3(PO_4)_2(OH,H_2O)_6$

Creamy white florencite-(Ce) crystals up to 1 cm were found a few years ago, together with pyrite and color-changing monazite-(Ce), in the Dolores Section gallery.

Fluorapatite $Ca_5(PO_4)_3F$

Fluorapatite, one of the most beautiful Llallagua minerals, used to be quite abundant as colorless to purple or pink, translucent to transparent, tabular to prismatic crystals, although fine specimens are almost unobtainable now. It was the principal gangue mineral in some of the richest cassiterite veins mined in the 1920's, and is considered to be the precursor from which the extensive suite of other phosphates (vauxite, paravauxite, metavauxite, wavellite, variscite, crandallite, childrenite, vivianite and allophane) developed, except for monazite and xenotime. Bandy (1944) observed that fluorapatite is mostly confined to veins in the sedimentary rocks and the igneous rocks near the sedimentary contacts.

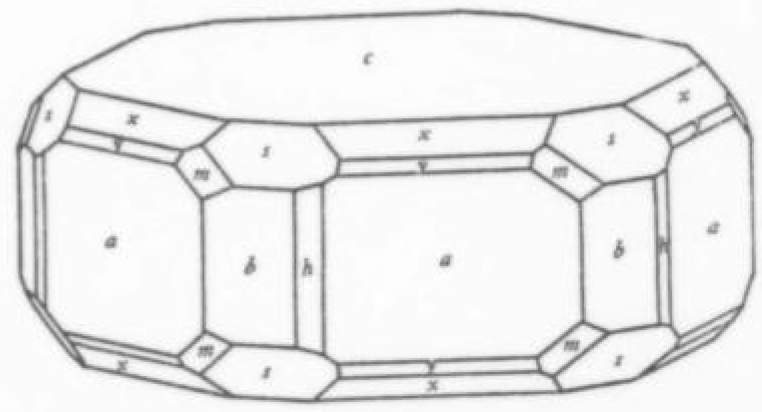


Figure 35. **Fluorapatite from Llallagua; crystal drawings by Gordon (1944).**

Fluorapatite crystals to several centimeters have been found emplanted on quartz and ferberite crystals in many vugs in various veins. The most prolific source of fine fluorapatite specimens has been the Contacto vein, especially the area above Level 295, where large, colorless, transparent to translucent crystals to 5 cm were found in vugs. The crystals, showing a habit composed of nine different forms, range in proportion from equant to thin tabular. Most fluorapatite is covered by a crust of wavellite which can be flaked off. Tabular crystals from the Animas vein (Level 235) show color zoning, from colorless in the core to pink to purple in the outermost zone. In the 1930's large, fine pink fluorapatite crystals were found along the Bismarck vein (above Level 383). In the early 1940's small crystals were found abundantly on Levels 411 and 446. Some crystals are preferentially frosted on the faces of

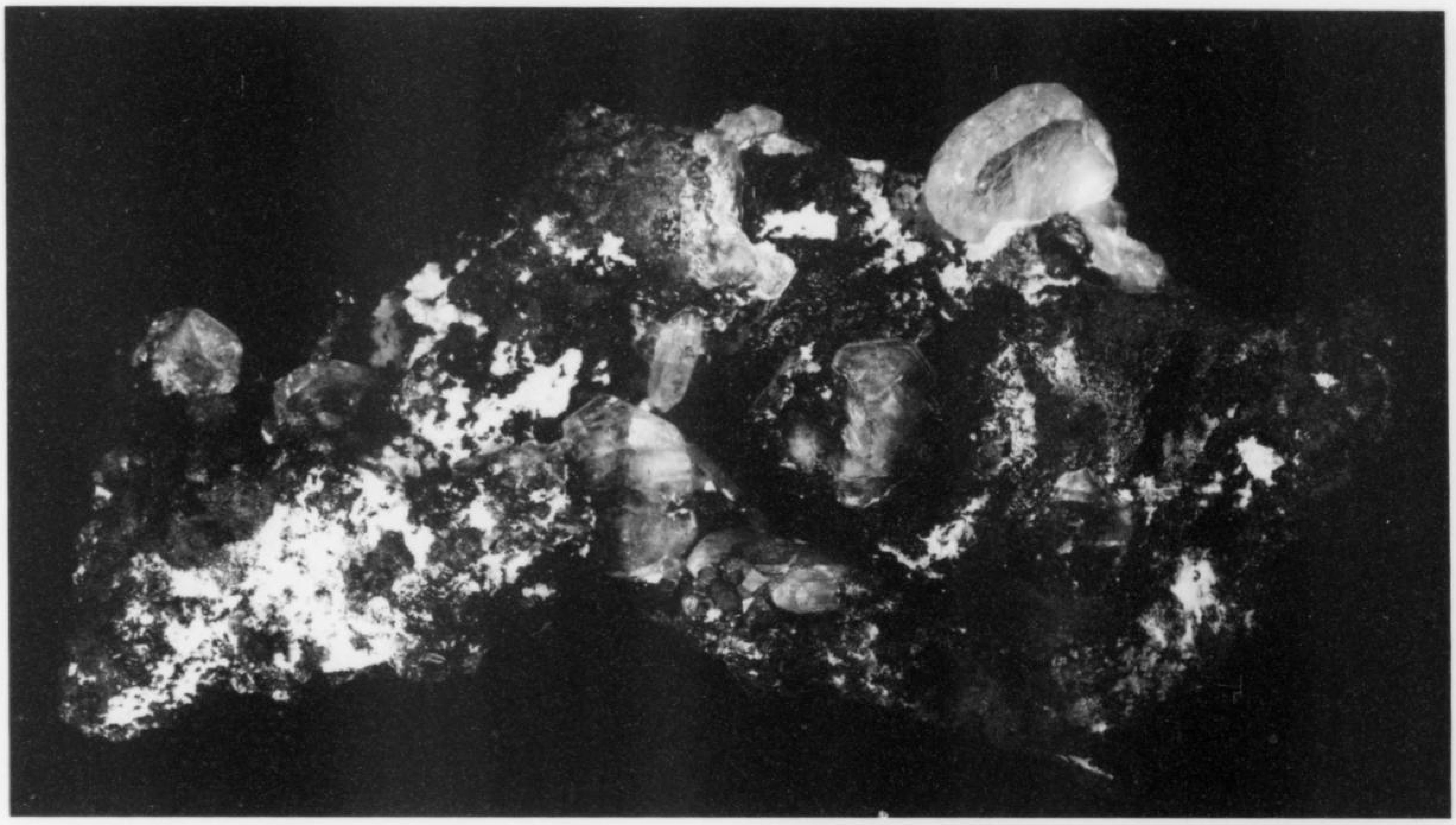


Figure 36. **Colorless fluorapatite crystals on stannite with jeanbandyite, 11 cm, from the Contacto vein, Llallagua. Bandy collection, Natural History Museum of Los Angeles County; Anthony Kampf photo.**

Figure 37. **Colorless fluorapatite crystal, 4.7 cm, from the Contacto vein, Llallagua. Bandy collection, Natural History Museum of Los Angeles County; Anthony Kampf photo.**

Figure 38. **Fluorapatite crystal group, 2.5 cm, from Llallagua. Seaman Mineral Museum collection, Michigan Technological University; John Jaszczak photo.**

Figure 39. **Colorless fluorapatite crystal, 3 cm, from Llallagua. Hyrsl collection and photo.**

Figure 40. Purple fluorapatite crystal, 5.3 cm, on matrix, from Llallagua. Collection of the Geology Museum, Colorado School of Mines, Golden (acquired 1982); photo by John Smolski.

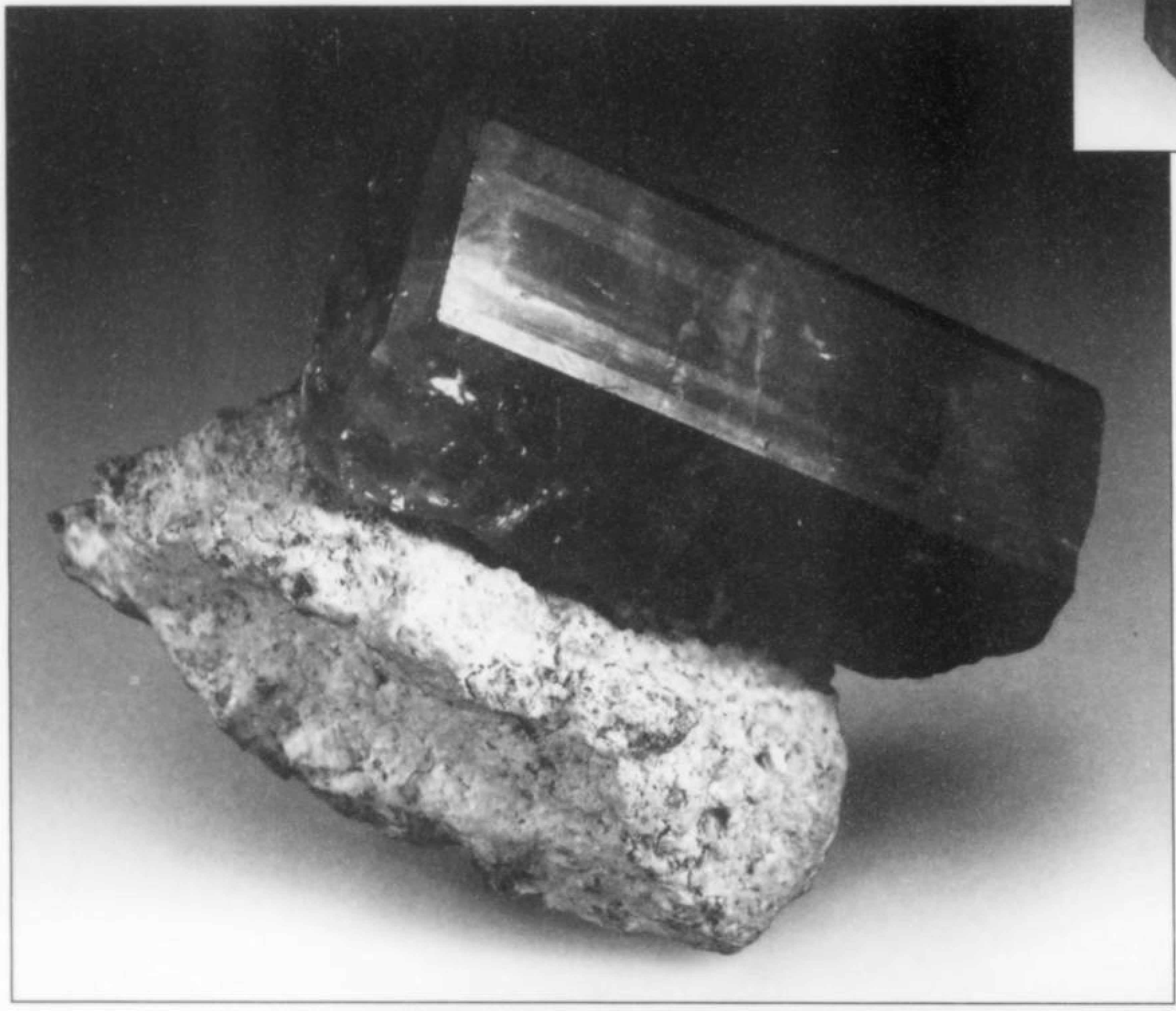


Figure 41. Purple fluorapatite crystal, 3.6 cm, from Llallagua. William Larson collection; Wimon Manorotkul photo.

Figure 42. Purple fluorapatite crystal, 3 cm, on matrix, from Llallagua. William Larson collection; Wendell Wilson photo.

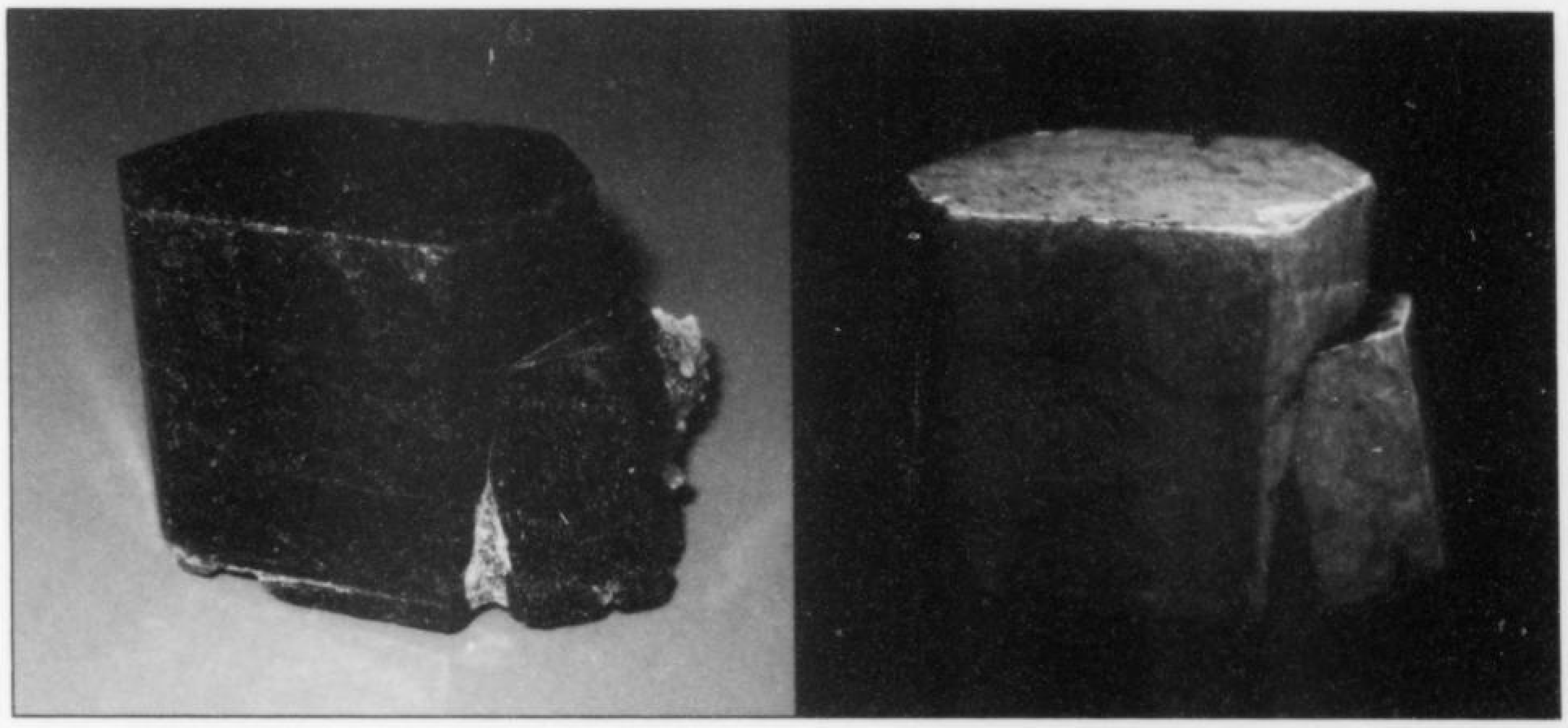


Figure 43. **Fluorapatite crystal from Llallagua, 3 cm, filled with jamesonite inclusions, and (*right*) showing differential fluorescence under shortwave ultraviolet light. John Rakovan specimen and photos.**

certain forms and lustrous on others (Bandy, 1944). Fluorapatite crystals from the Contacto vein (on Level 250 and above Level 295) commonly are on stannite matrix and have associated jeanbandyite. Crystals filled by fine jamesonite needles have also been found. Along the San José/San Firmin vein (Levels 516 to 481), flat tabular crystals altered to a white clay-like mineral are found embedded in cassiterite.

Llallagua fluorapatite has a very strong form-dependant fluorescence under ultraviolet light, yellow-orange on $\{10\bar{1}0\}$ faces and bright violet on $\{0001\}$ faces. This fluorescence was studied in detail by John Rakovan (2003), who also determined the age of the fluorapatite crystallization at about 43.8 Ma (million years). The crystals also exhibit an alexandrite-like effect: they are pale pink in daylight and tungsten light but lemon-yellow under fluorescent lighting, a phenomenon which indicates a high content of certain rare-earth elements.

The latest discovery, in 2002, yielded tabular fluorapatite crystals to 3 cm wide, but only about 4 mm thick, completely covered by yellow wavellite crusts.

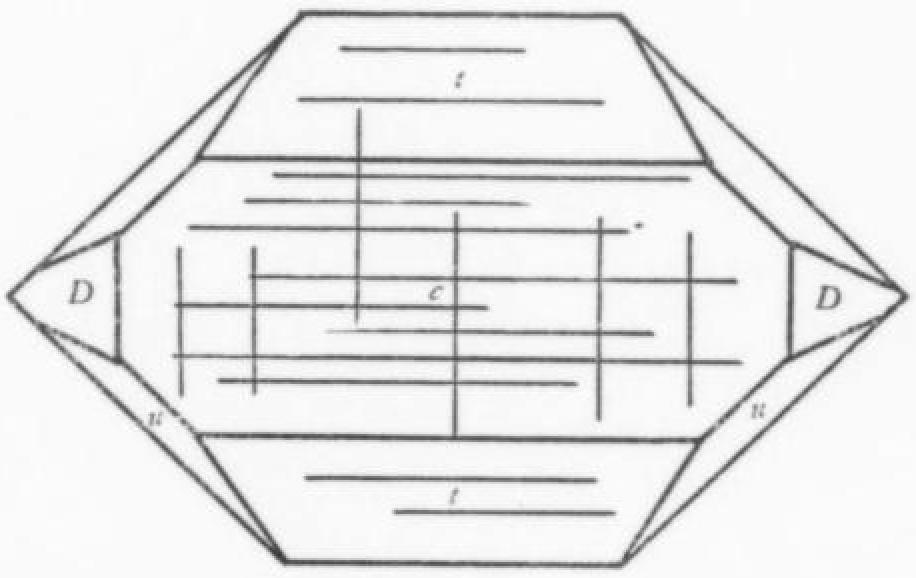


Figure 44. **Francheite from Llallagua; crystal drawing by Gordon (1944).**

Franckeite $Pb_6Sb_2FeSn_2S_{14}$

Franckeite occurs in small quantities throughout the Llallagua deposit, primarily as a minor component of pyrite/marcasite replacements of pyrrhotite. It has been found commonly as tabular to platy, brilliantly metallic crystals and thin, black, flexible laminae resembling graphite, usually in association with marcasite and wurtzite. Vuggy masses of franckeite lined with drusy franckeite crystals from 2 to 5 mm are currently the main ore in one portion of the Contacto vein, where franckeite is associated with pyrite, arsenopyrite, wurtzite and rare cylindrite. It also occurs abundantly in the Plata vein. Bandy (1944) reported "heavy crystals" found in the early 1940's in the Inca vein above Level 180, associated with brilliant prismatic crystals of cassiterite.

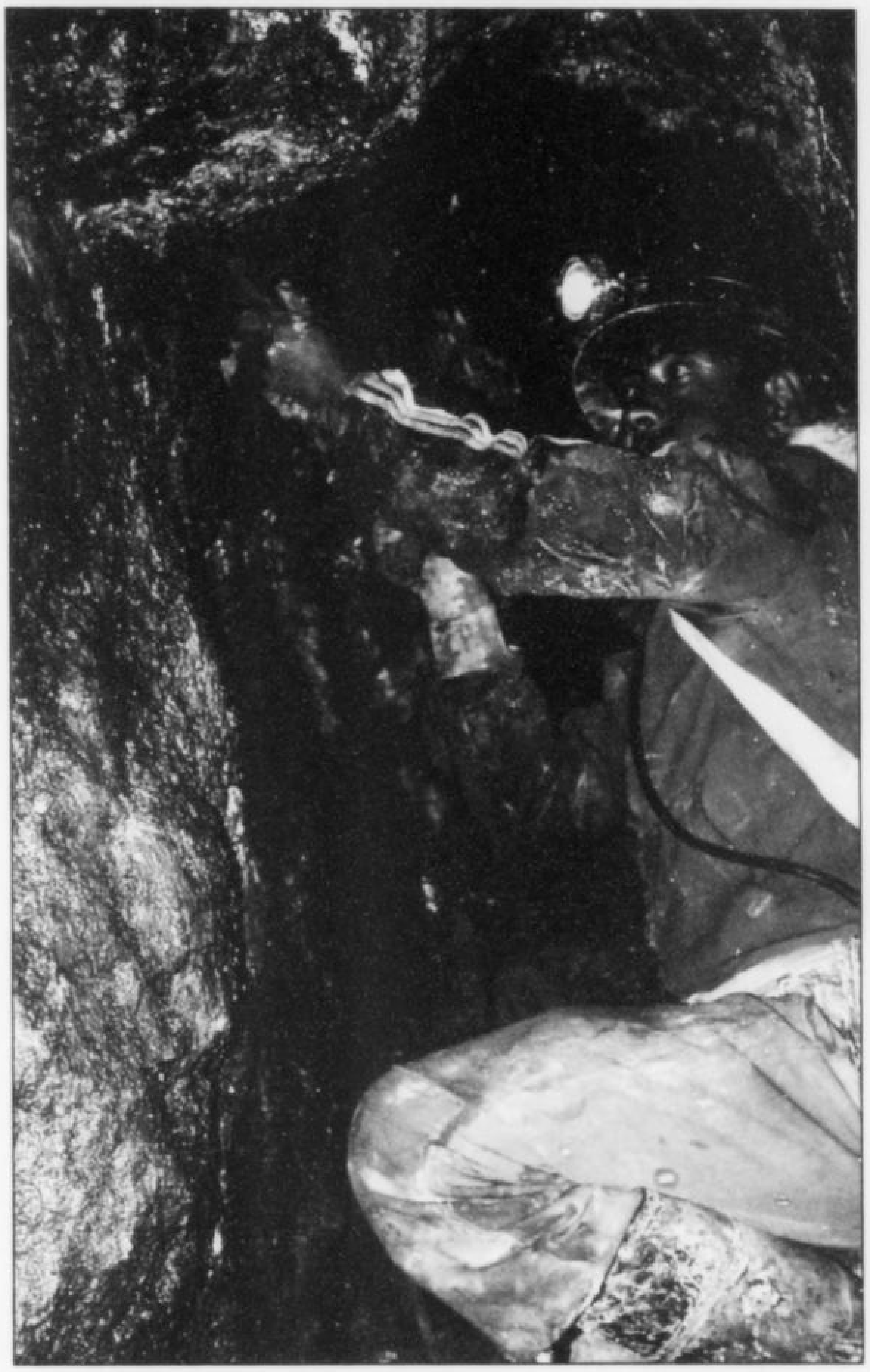


Figure 45. **A Llallagua miner working a franckeite vein. Hyrsl photo.**

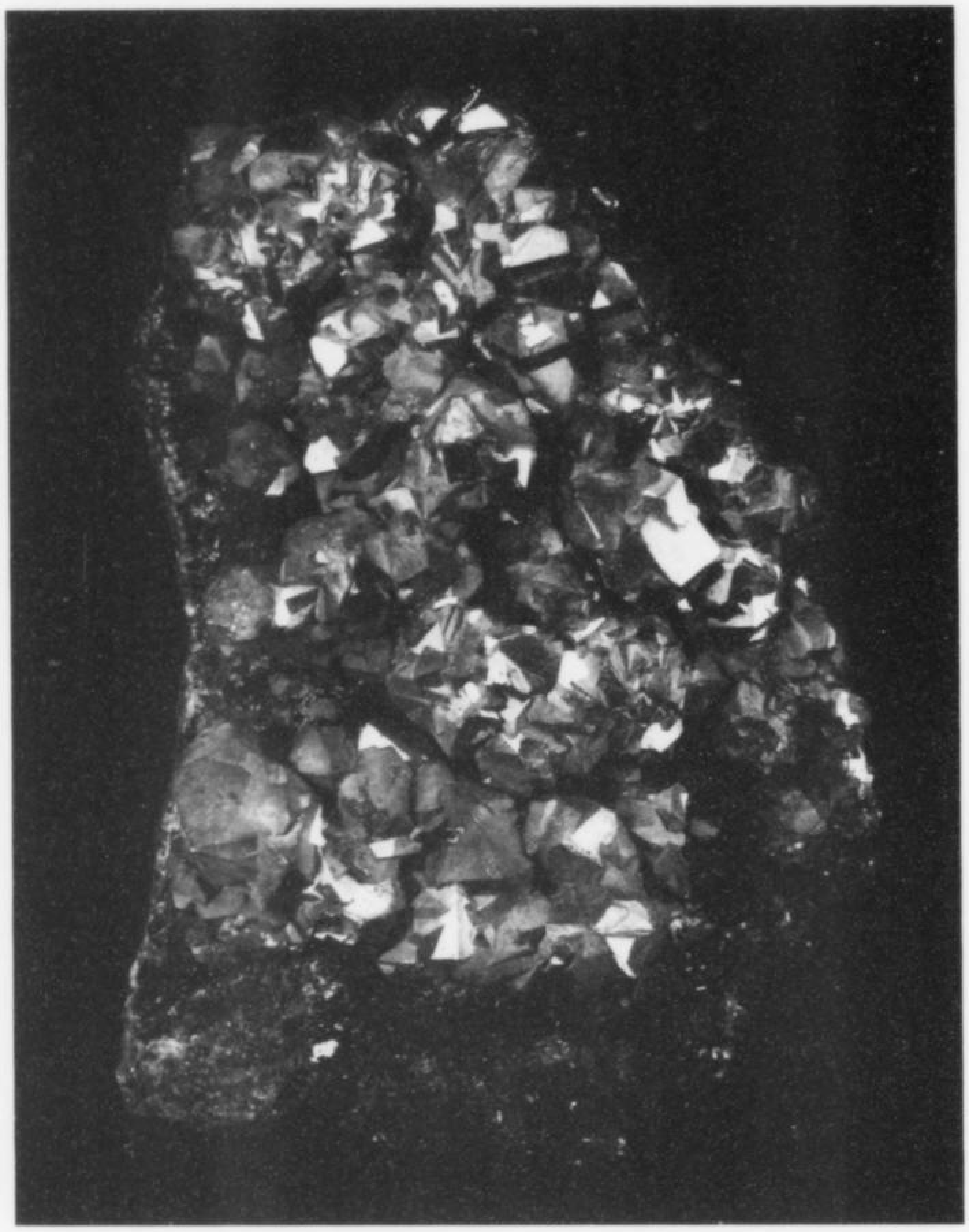


Figure 46. **Galena (penetration twins) on matrix, 8 cm, from the Mujer Loca tunnel, Llallagua. Bandy collection, Natural History Museum of Los Angeles County; Anthony Kampf photo.**

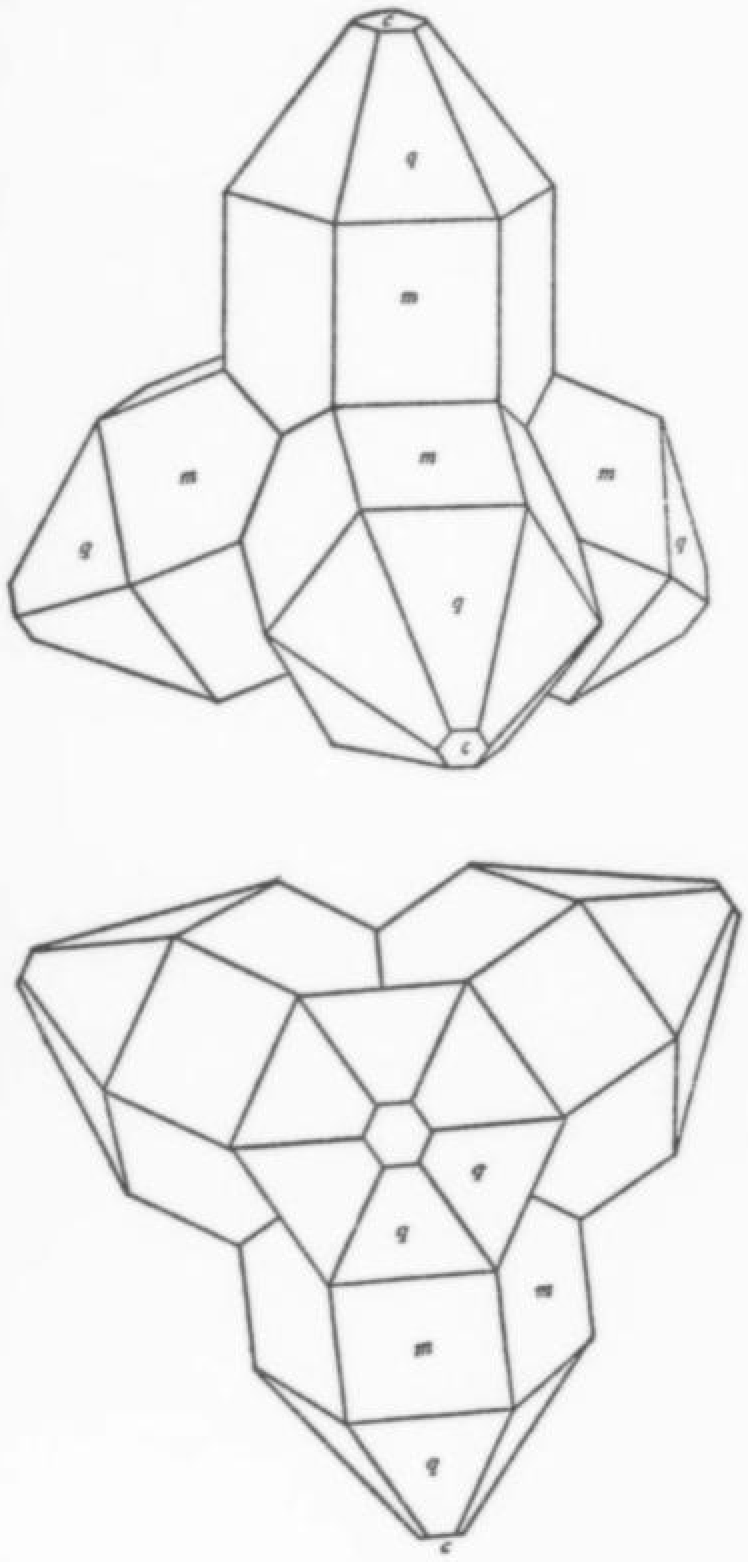


Figure 47. **Greenockite from Llallagua; crystal drawings by Gordon (1944).**

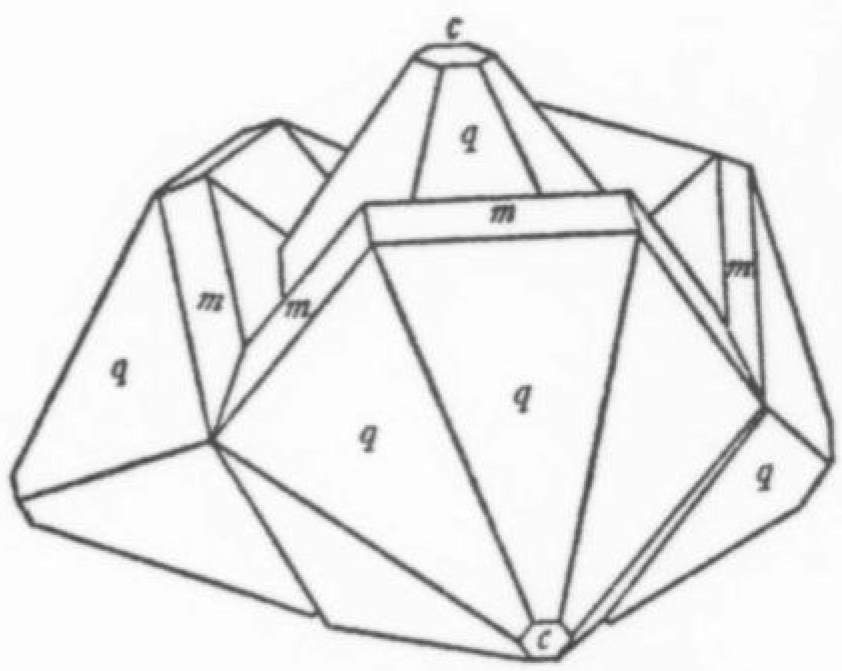


Figure 48. **Greenockite from Llallagua; crystal drawings by Gordon (1944).**

Galena PbS

Galena is rare at Llallagua. Bandy (1944) mentioned crystals to 5 mm from the La Loca gallery, 400 meters from the intrusive stock.

Goethite α-$Fe^{3+}O(OH)$

Goethite has been found as nodules up to 2 cm in diameter, formed by radiating, brownish black fibrous crystals.

Greenockite CdS

Greenockite is widespread in small quantities as tiny pyramidal crystals, sometimes tightly grouped as thin crusts, and as rare twins. Greenockite from Llallagua (as at other Bolivian deposits) is bright brick-red, resembling vanadinite in color, in contrast to the yellow color typical of other world localities. Specimens with minute red greenockite crystals (0.1 mm) sprinkled on wavellite, quartz, cassiterite or marcasite are now widely distributed in micromount collections. It also occurred as orange, mammillary aggregates to 1 cm on cassiterite and quartz, with variscite and wavellite. Greenockite at Llallagua appears to have been deposited hydrothermally as a late-stage primary mineral, rather than being a decomposition product of cadmian sphalerite; no secondary source of cadmium has been found.

Crystals are typically hexagonal pyramidal and hemimorphic, in some cases with prism faces, and sometimes grouped interestingly in cyclic "tetrapod" twins on $(10\bar{1}\bar{2})$, composed mainly of $\{10\bar{1}0\}$ prism faces and $\{50\bar{5}3\}$ pyramids, with tiny *c*-faces.

Greenockite at Llallagua is widespread in small quantities, in all the veins but especially in the richer ore shoots where it coats marcasite and wavellite. The Forastera vein (Levels 481 and 516), the Riggins vein, the Inca vein, the Bismarck vein (Level 411), the Animas vein and the San José vein in particular have all been important sources of specimens (Bandy, 1944).

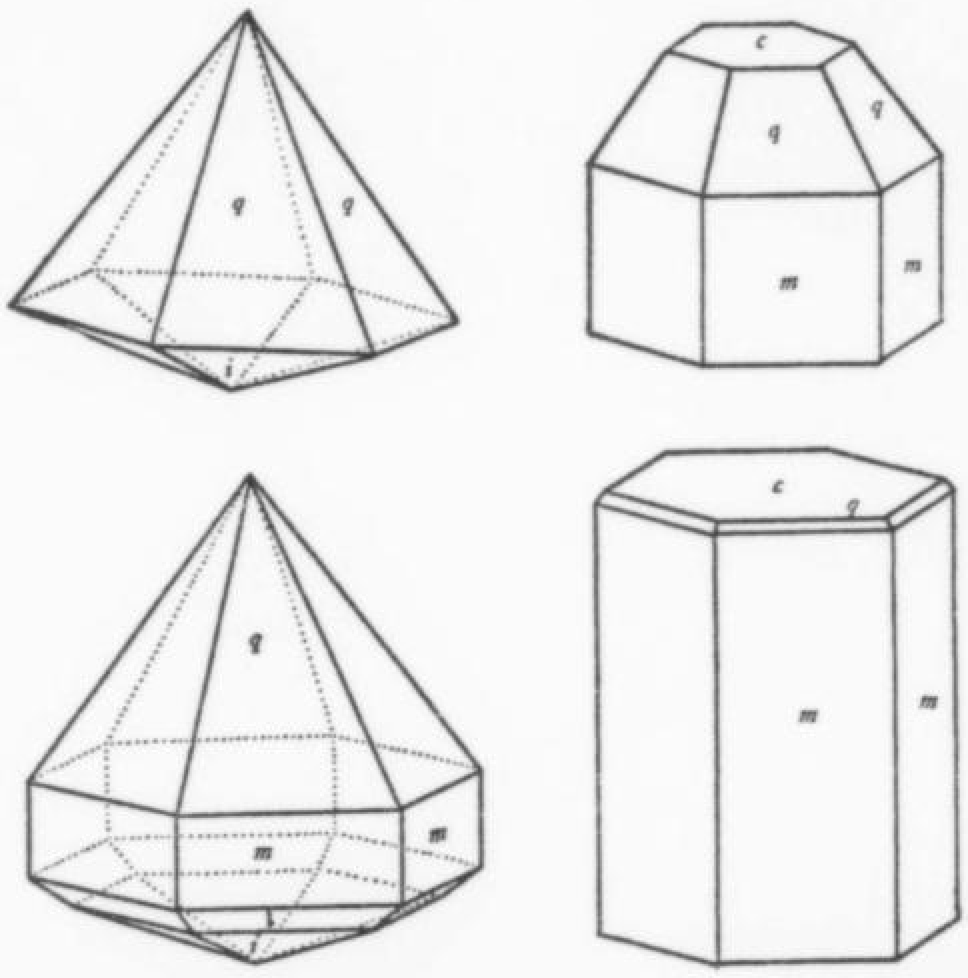


Figure 49. **Greenockite from Llallagua; crystal drawings by Gordon (1944).**

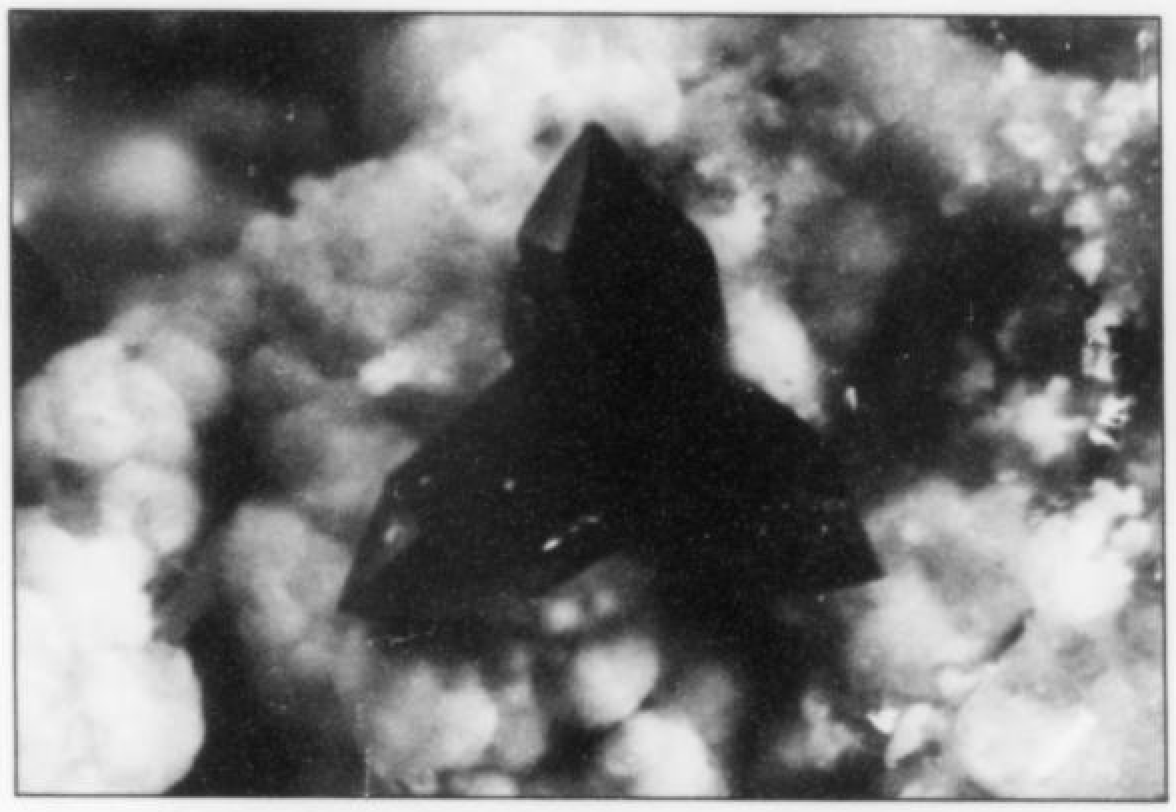


Figure 50. **Greenockite "tetrapod twin" (showing three of the four members), 0.3 mm, from Llallagua. Weber-Perlof collection, Natural History Museum of Los Angeles County; Anthony Kampf photo.**

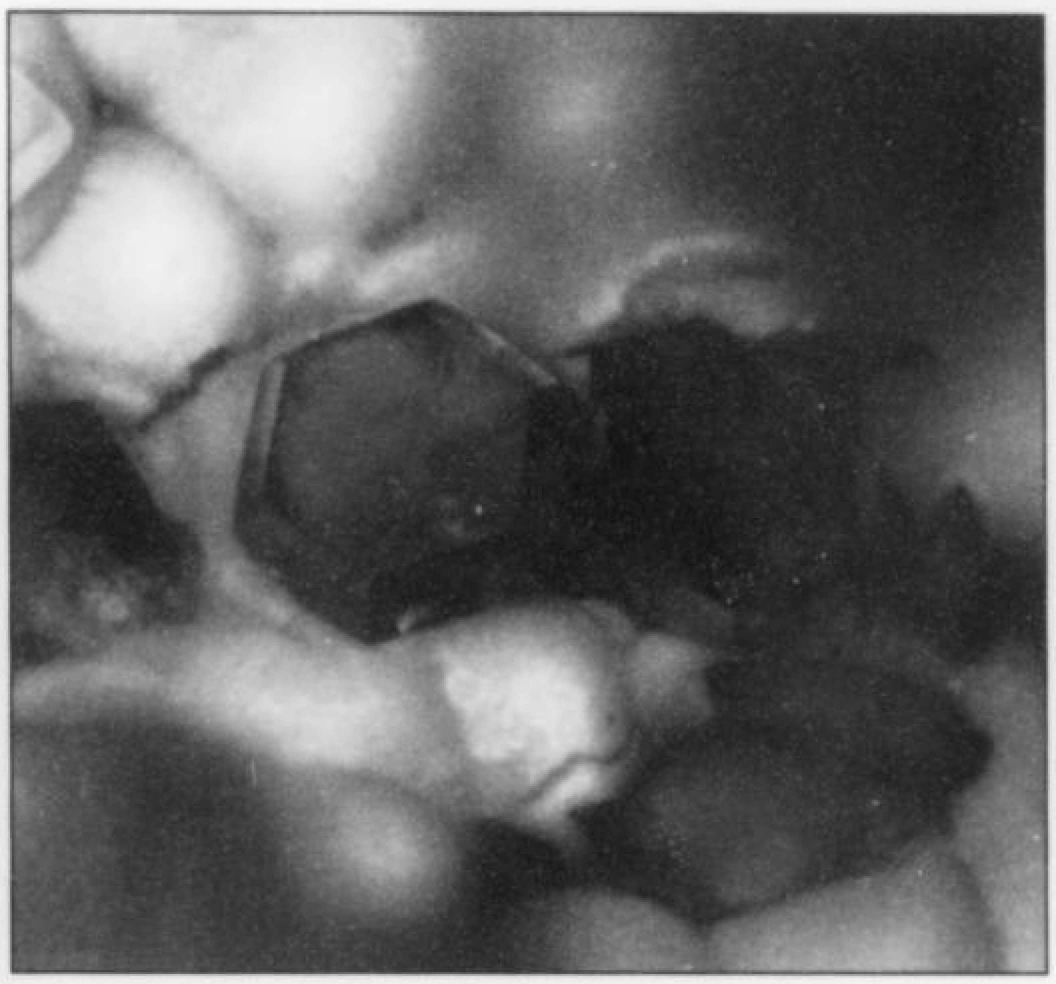


Figure 51. **Tabular orange-red greenockite crystals to 0.1 mm. Ex Fred and Alice Kraissl collection; John Jaszczak collection and photo.**

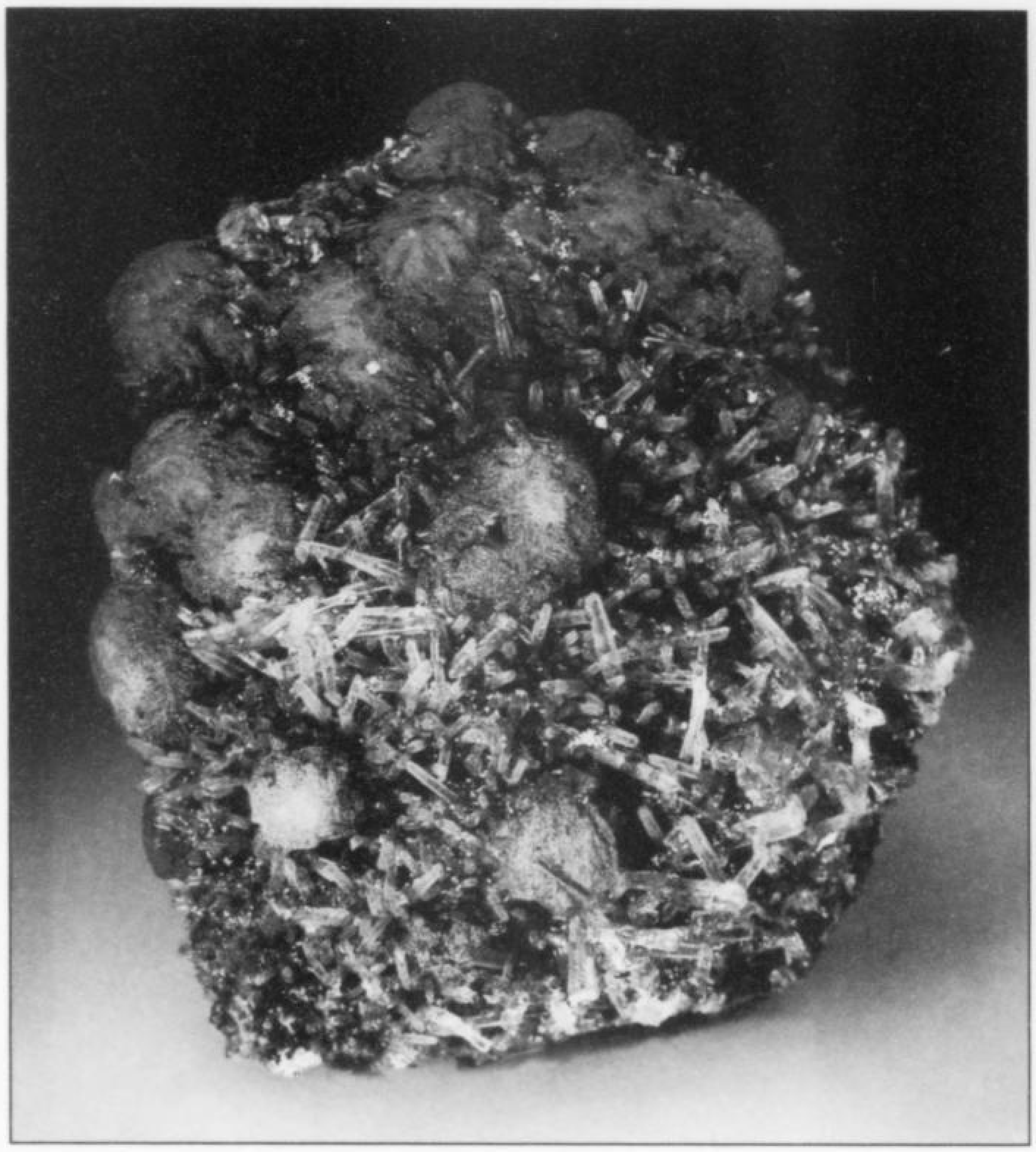


Figure 52. **Greenockite on quartz, 5.5 cm, from Llallagua. Bandy collection, Natural History Museum of Los Angeles County; Anthony Kampf photo.**

Gypsum $CaSO_4 \cdot 2H_2O$

A few specimens of unusual pseudomorphs of gypsum after tabular fluorapatite crystals to about 3 cm in diameter were found in 2002. Since the pseudomorphs were found adjacent to decomposing pyrite, they probably formed by exposure to acidic sulfate-rich water.

Hagendorfite $NaCaMn^{2+}(Fe^{2+},Fe^{3+},Mg)_2(PO_4)_3$

Hagendorfite has been reported from Llallagua by Petrov *et al.* (2001), on the basis of information on specimen labels. However, confirmation of the source is lacking. Therefore the occurrence at Llallagua must be considered doubtful.

Halotrichite $FeAl_2(SO_4)_4 \cdot 22H_2O$

Both halotrichite and pickeringite crystallize as post-mining formations in old galleries. Bandy (1944) observed that they started growing as loose fibrous masses on walls in dry parts of the mine almost immediately after the workings were abandoned, the formations reaching 2.5 cm long after 3 weeks, and up to 20 cm in one year.

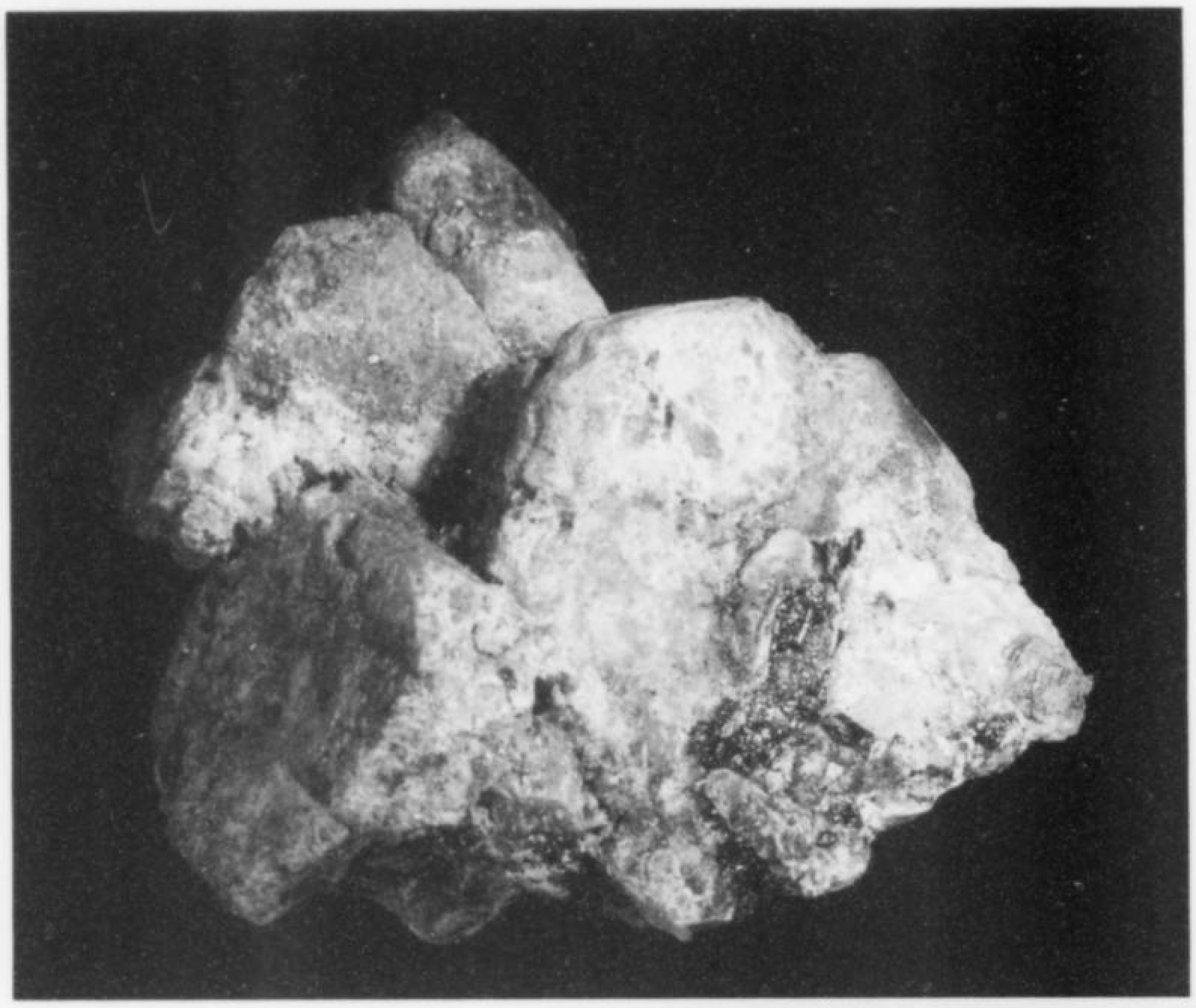


Figure 53. **Gypsum pseudomorphs after fluorapatite crystals, 7 cm, from Llallagua. Hyrsl collection and photo.**

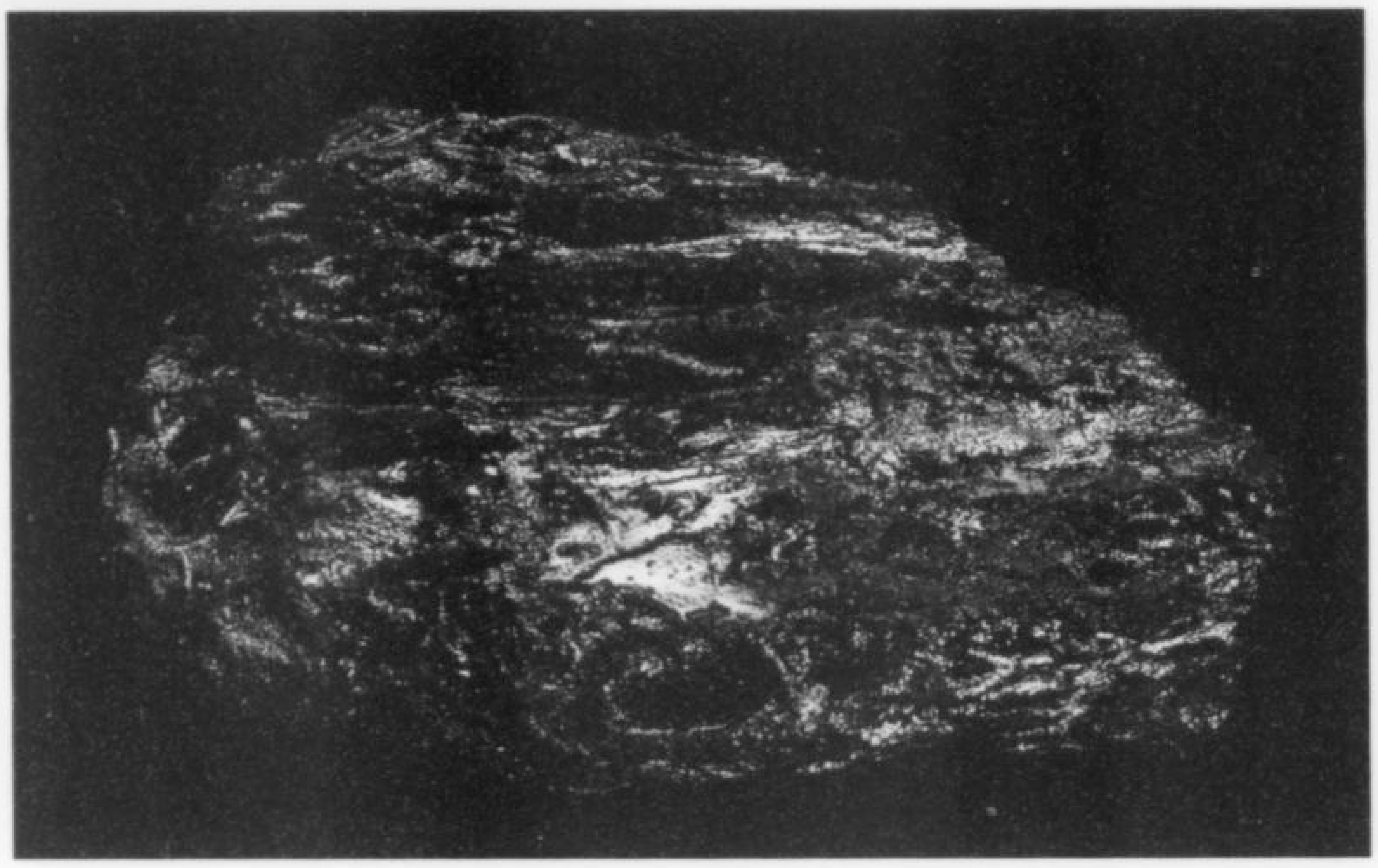


Figure 54. **Hematite with irridescent goethite alteration (the mixture formerly known as "turgite"), 7.2 cm, from Llallagua. Les Wagner, Jr. collection; Jeff Scovil photo.**

Hematite Fe_2O_3

Rosettes of tabular hematite crystals to 1 cm can be found embedded in slightly metamorphosed red shales within a few hundred meters east of the contact between the shales and the volcanic stock (Bandy, 1944).

Hinsdalite $(Pb,Sr)Al_3(PO_4)(SO_4)(OH)_6$

White, spherical crystal sprays up to 1 mm diameter on drusy franckeite and pyrite from the Dolores Atras Section were recently identified as hinsdalite.

Hisingerite $Fe_2Si_2O_5(OH)_4 \cdot 2H_2O$

Reddish to brown, gum-like amorphous masses of hisingerite are common at Llallagua, sometimes associated with cronstedtite. Hisingerite can be soft and plastic when first found underground, but rapidly becomes hard and very brittle after removal from the mine.

Hübnerite $(Mn,Fe)WO_4$

Red-brown hübnerite crystals, rarely twinned, have been found in superficial parts of some veins (Bandy 1944).

Jamesonite $Pb_4FeSb_6S_{14}$

Jamesonite is widespread as metallic fibers in those veins which transect sedimentary rock. It has even been found as dense inclusions in some younger fluorapatite and vivianite crystals.

Jarosite $KFe_3(SO_4)_2(OH)_6$

Massive yellow jarosite has been found with limonite in the centers of larger veins, and straw-yellow, compact masses of porcelaneous texture can now be found in oxide-zone material in the upper levels of block-caving rubble. Much rarer are the small brown jarosite crystals found in the Blanca vein.

Jeanbandyite $(Fe^{3+},Mn^{2+})(Sn^{4+})(OH)_6$

Jeanbandyite was described by Kampf (1982) and named after Jean Bandy, who had donated her husband Mark Bandy's collection to the Natural History Museum of Los Angeles County. It is orange-brown and forms tiny (0.2 mm), epitactically oriented bipyramidal overgrowths on the corners of yellow octahedrons of wickmanite, in most cases completely enveloping the host crystal. The only forms observed are the pyramid {111} (striated parallel

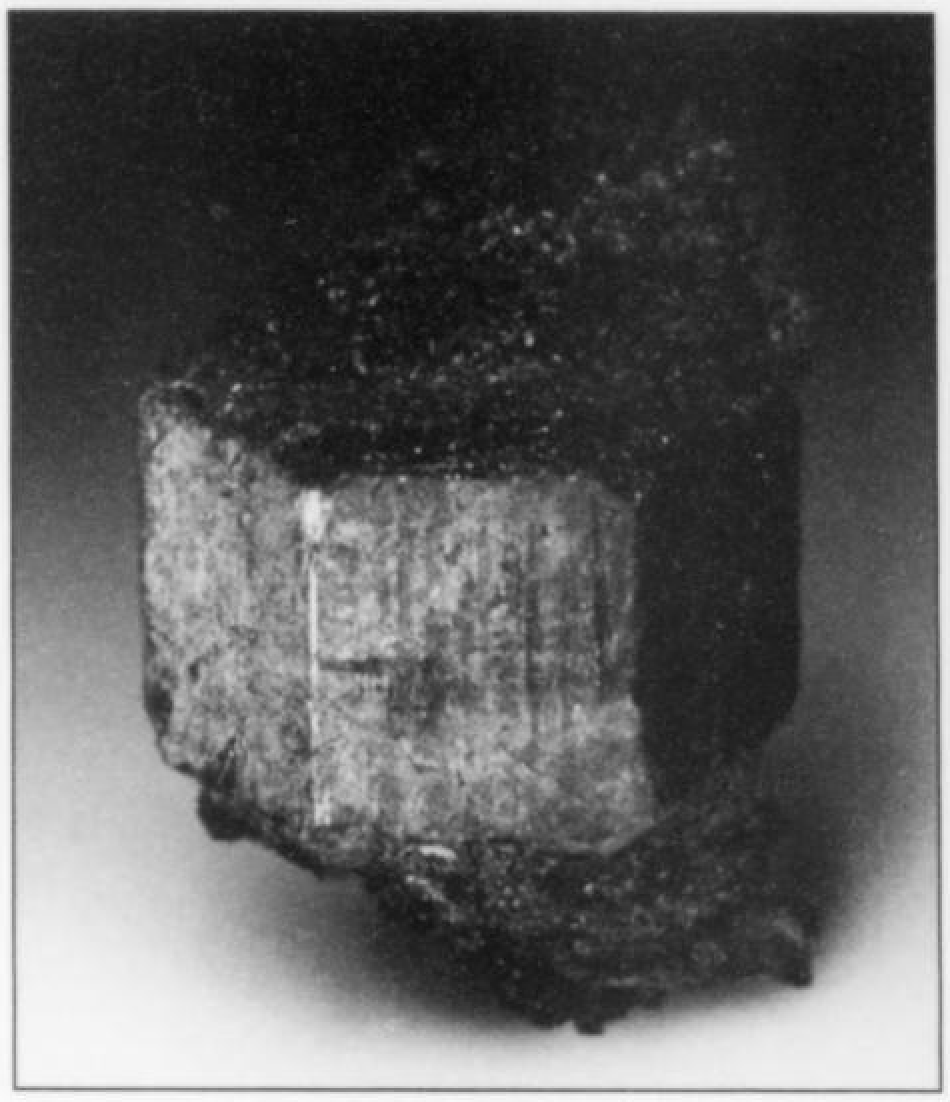


Figure 55. **Jamesonite-included fluorapatite crystal, 4 cm, from Llallagua. Hyrsl collection and photo.**

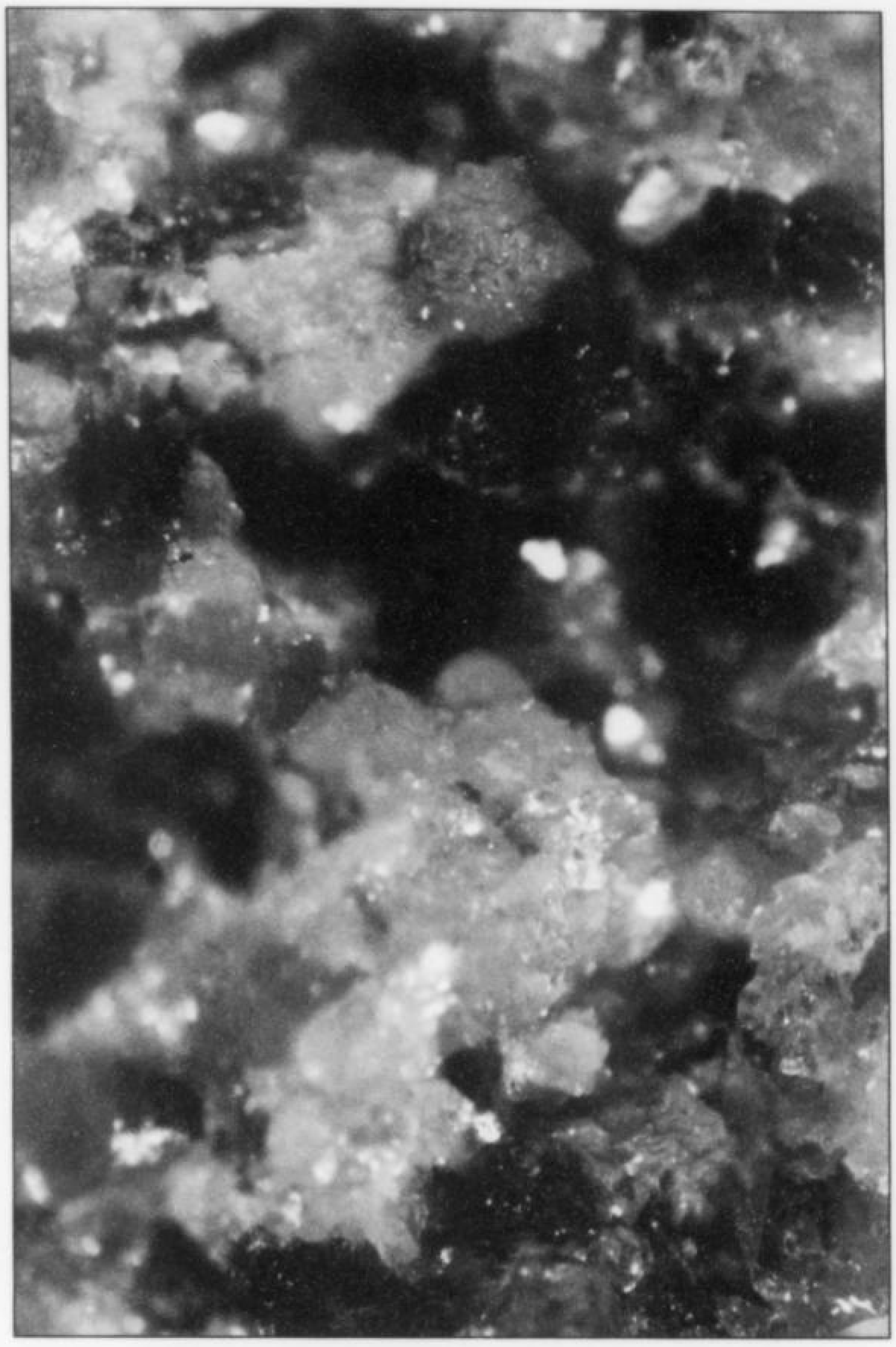


Figure 57. **Jeanbandyite crystals, 3.5 mm, with plumbogummite crust, from Llallagua. Hyrsl collection and photo.**

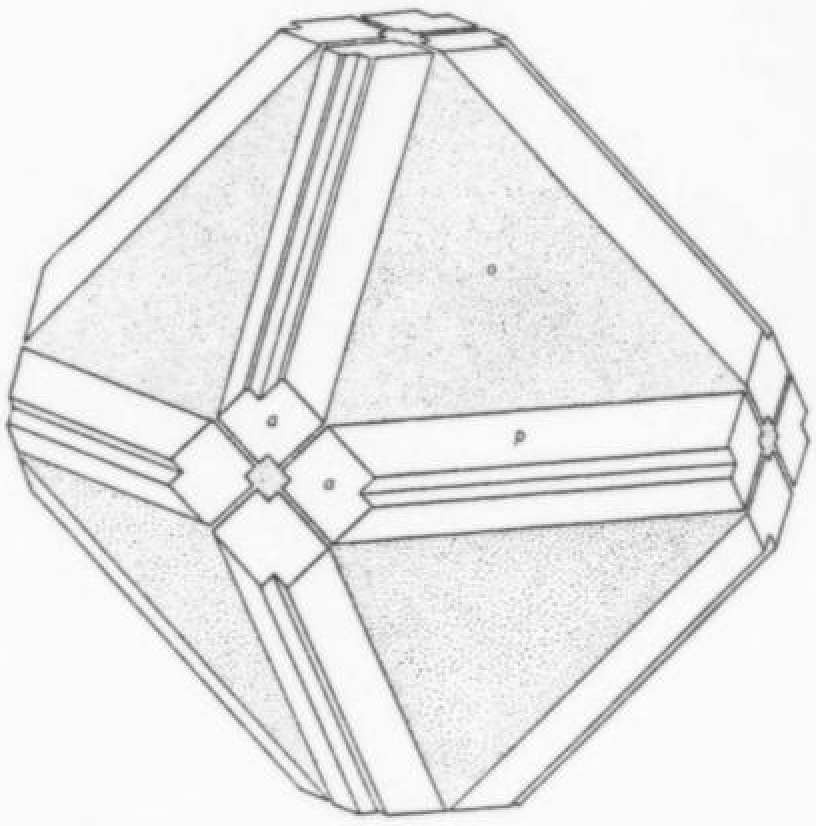


Figure 56. **Jeanbandyite epitactic on natanite, from Llallagua; crystal drawing by Gordon (1944).**

to [100]), pinacoid {001} (parallel to the cube face of the host) and prism {100}. Jeanbandyite is tetragonal pseudo-cubic with extremely low birefringence and cell constants *a* and *c* so similar to each other as to be indistinguishable.

The species was identified on 36 specimens of massive stannite in the Bandy collection, most of which contain prominent crystals of colorless, blocky to tabular fluorapatite to 5 cm. Well-formed crystals of stannite to 2 mm line pockets in this matrix, along with crystals of pyrite, jamesonite, cassiterite, quartz and crandallite.

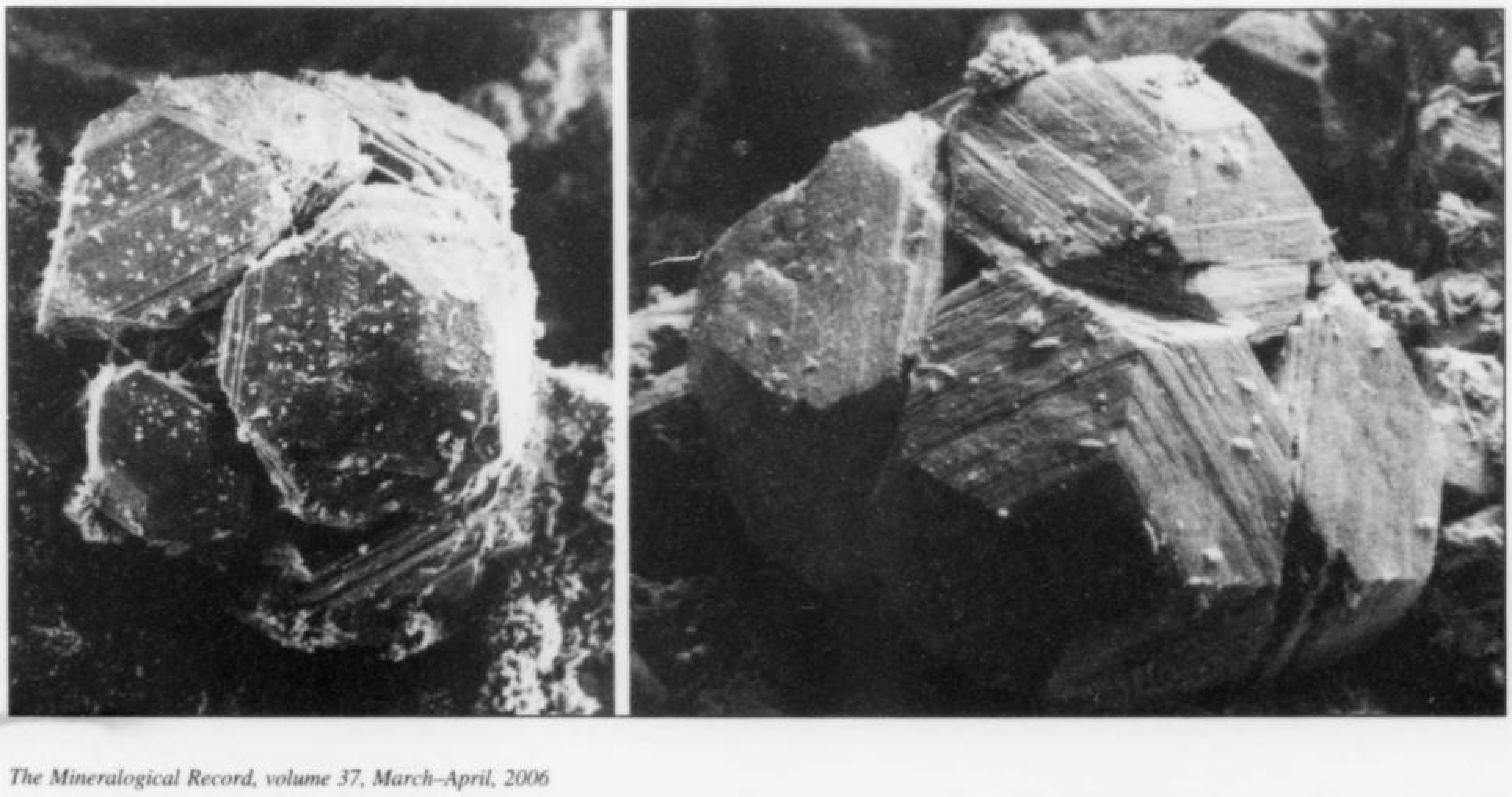


Figure 58. **Jeanbandyite epitactic on wickmannite, about 0.2 mm, from Llallagua. Bandy collection, Natural History Museum of Los Angeles County; Carol Stockton SEM photo.**

These specimens were collected from large vugs on and above Level 295 of the Contacto vein. Most existing specimens of the mineral were probably collected by Bandy at this location, but jeanbandyite has also been identified on Level 250 of the Contacto vein and Level 295 of the Contacto-Dolores vein, with fluorapatite, stannite and cassiterite. Twelve meters above Level 411 of the Bismarck vein it has been found with wolframite, bismuthinite, stannite and pyrite. And 20 meters above Level 160 of the Plata vein it has been found with franckeite, stannite and pyrite.

Gordon (1944) figured an isotropic octahedral crystal of an unknown species, probably natanite (he cited an index of refraction of 1.745; natanite equals 1.755), with epitactic overgrowths of an unknown tetragonal mineral along the octahedron edges. The tetragonal mineral is similar to jeanbandyite in that it is of low birefringence and uniaxial negative, showing {100} (actually {001}?) parallel to the host cube {100} face and the tetragonal pyramid {111} parallel to the host octahedral {111} face. Gordon indicates a refractive index "similar" to that of the host crystal, 1.745, whereas the indices of jeanbandyite are $\varepsilon = 1.833$ and $\omega = 1.837$. Nevertheless, Kampf (1982) identifies specimens of jeanbandyite overgrowths on natanite from Santa Eulalia, Chihuahua, Mexico, so it is distinctly possible that Gordon's optical measurement was somehow in error.

Jeanbandyite has since been found on the dumps in a completely different paragenesis, as crudely formed orange octahedrons covered by an orange plumbogummite crust, associated with hemispheres of banded "wood tin" cassiterite, quartz, pyrite and muscovite.

Kaolinite $Al_2Si_2O_5(OH)_4$

White kaolinite clay from Llallagua was described by Gordon (1944).

Linarite $PbCu(SO_4)(OH)_2$

Bandy (1944) described bright blue crusts of a mixture of linarite and caledonite near Level 355 of the Salvadora shaft.

Malachite $Cu_2(CO_3)(OH)_2$

Gordon (1944) found malachite needles with azurite on weathered chalcopyrite.

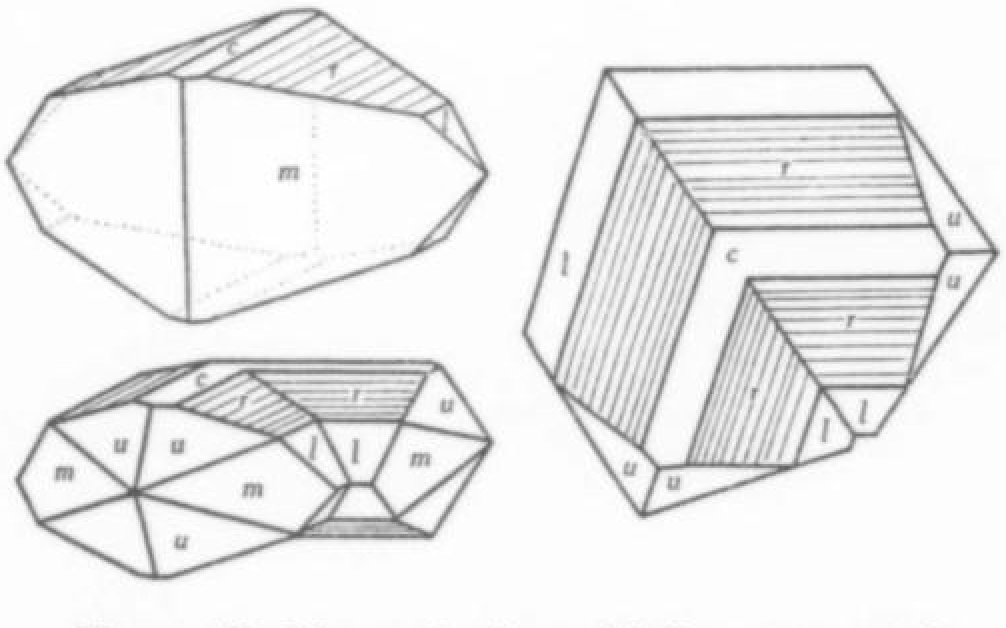


Figure 59. **Marcasite from Llallagua; crystal drawings by Gordon (1944).**

Marcasite FeS_2

The most interesting Llallagua marcasites are tabular pseudomorphs after pyrrhotite crystals to 20 cm, covered by wavellite, and paper-thin crystals interleaved with equally thin franckeite layers. In Bandy's time, when deeper sulfide-rich levels were being worked, marcasite was abundant, and its decomposition has caused serious problems on specimens in the Bandy collection; luckily, it is much less common in the upper levels which are currently producing specimens.

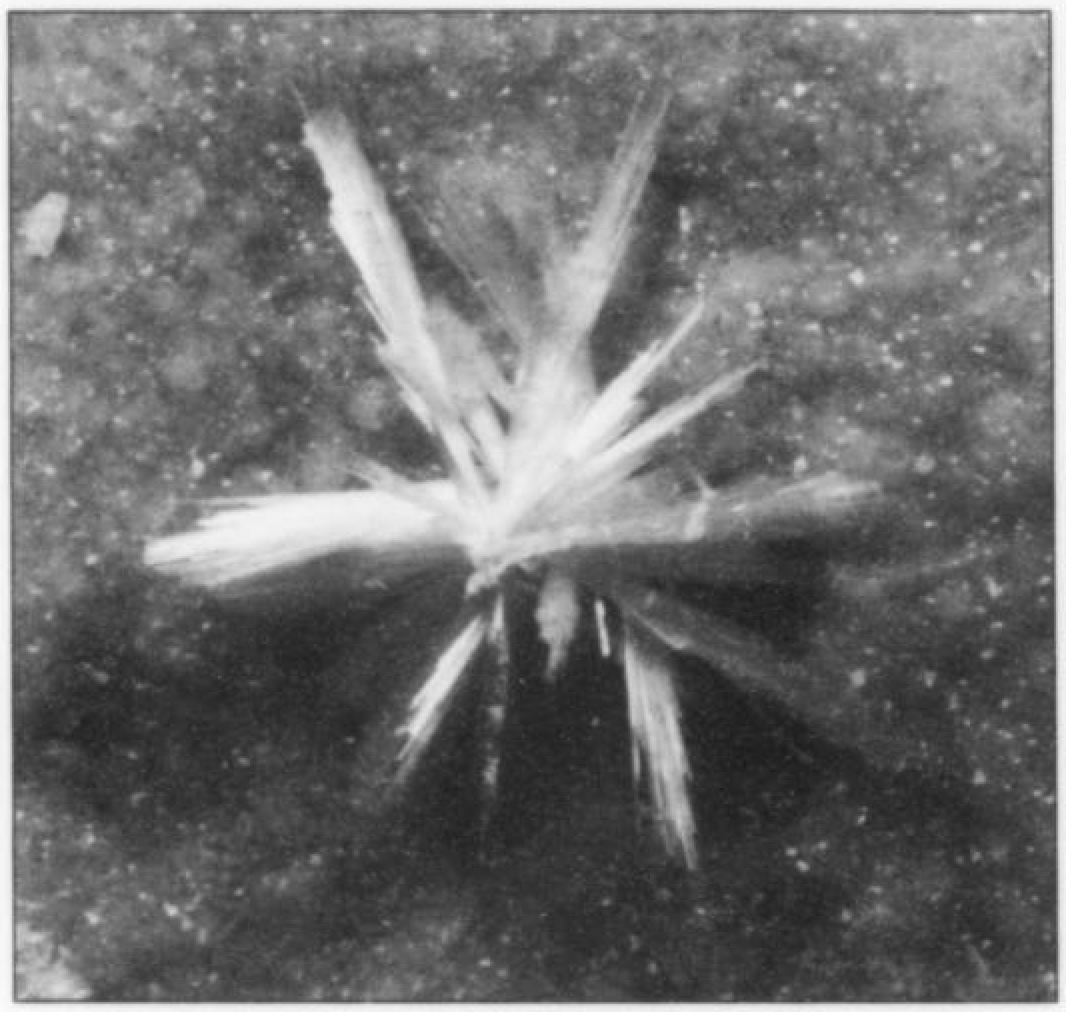


Figure 60. **Metavauxite crystal spray, 1.1 cm, on wavellite crust, from Branch AK, stope 43110, Llallagua. Seaman Mineral Museum collection, Michigan Technological University; George Robinson photo.**

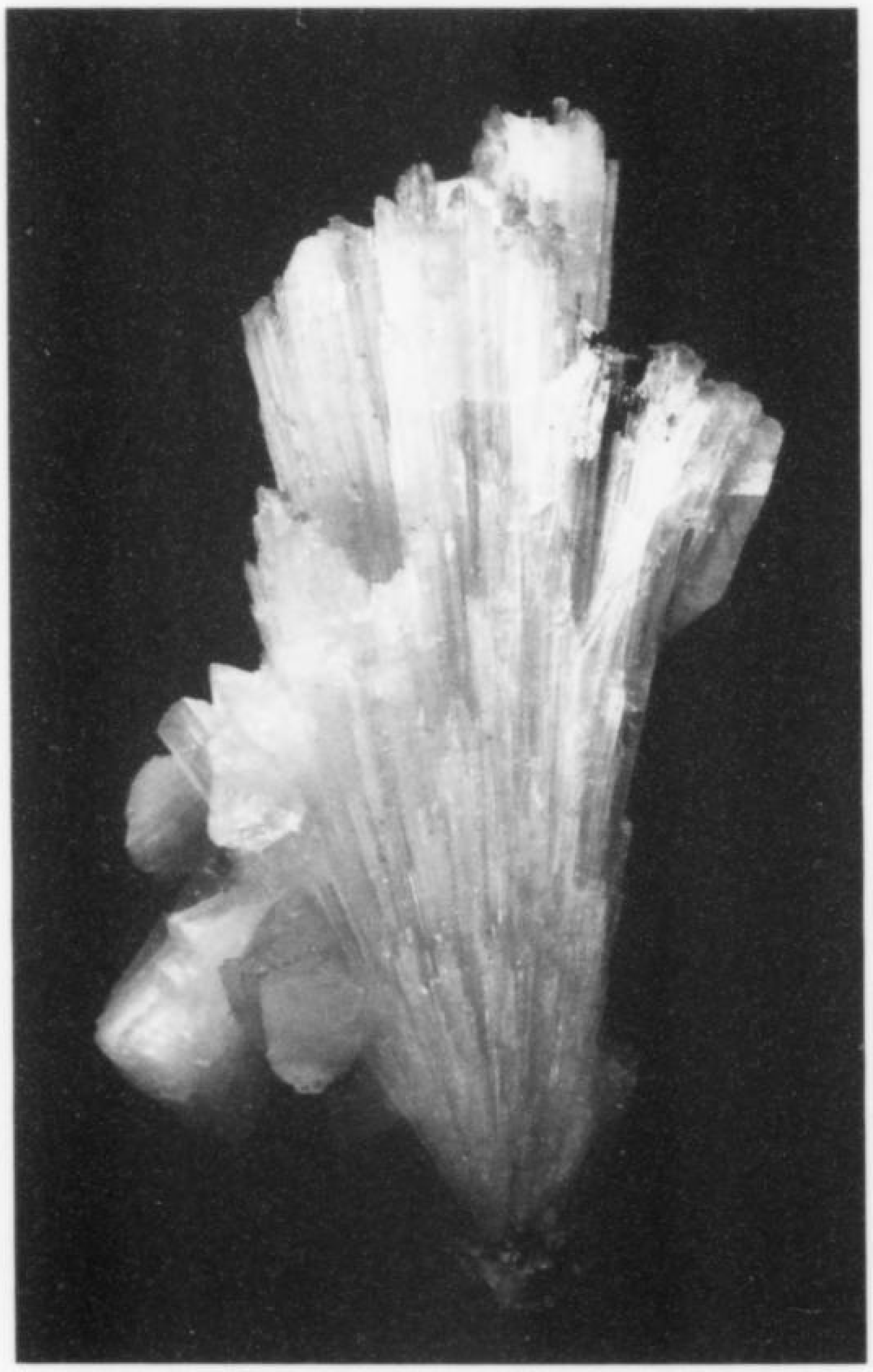


Figure 61. **Green spray of metavauxite crystals with blocky paravauxite crystals, from Llallagua. Ron Pellar collection; Jeff Scovil photo.**

Marcasite crystals are plentiful but small, rarely more than about 1 mm in size. They are usually twinned on (101) or (110); the (101) twins are sometimes reticulated with an orientation inherited from

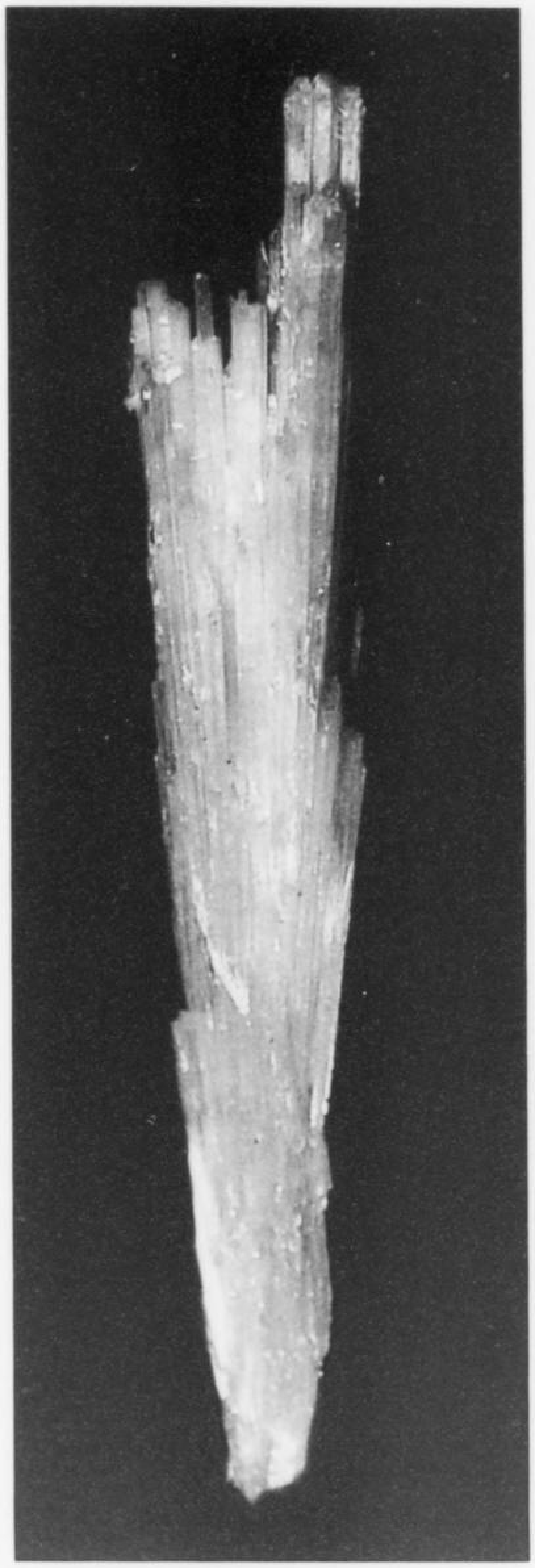


Figure 62. **Metavauxite crystal spray, the largest known (5 cm), from Llallagua. Chromy Fund purchase, Natural History Museum of Los Angeles County; Anthony Kampf photo.**

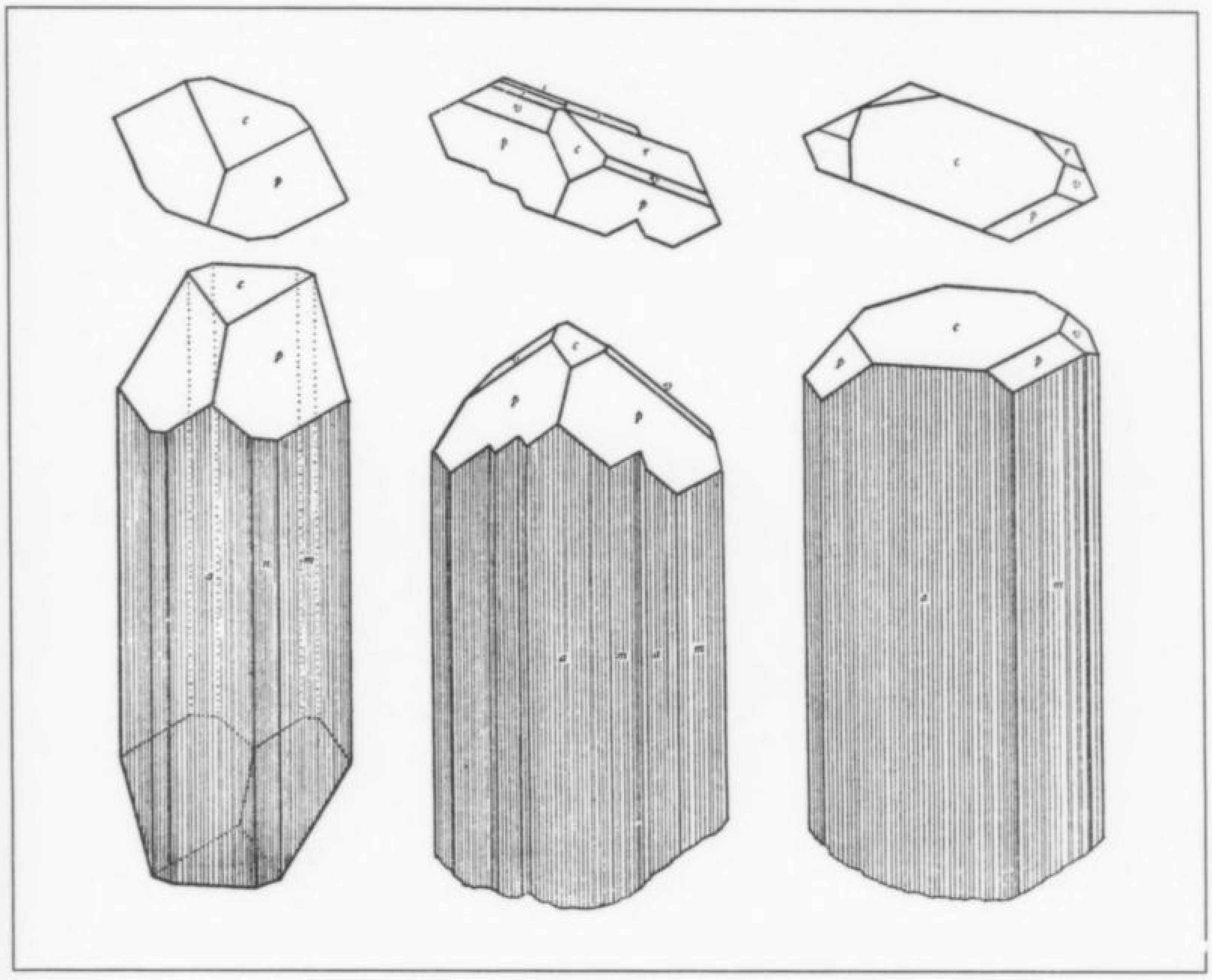


Figure 63. **Metavauxite from Llallagua; crystal drawings by Gordon (1944).**

the parent pyrrhotite crystal. Epitactic overgrowths of marcasite on pyrite are also known, with the *c* axis of the marcasite parallel to one of the *a* axes of the pyrite. Balls of acicular marcasite crystals to 2 cm are also known (Gordon, 1944).

Melanterite $FeSO_4 \cdot 7H_2O$

Green melanterite stalactites are common throughout the mine, and rarely melanterite occurs as crystals to 2 cm. The deep blue cuprian variety is often mistakenly called "chalcanthite" by the miners.

Mélonjosephite $CaFe^{2+}Fe^{3+}(PO_4)_2(OH)$

Very rare mélonjosephite was identified by X-ray diffraction as brown grains and brown-green aggregates on vauxite and under paravauxite from a rich vauxite-allophane pocket found in 2001–2002.

Metavauxite $FeAl_2(PO_4)_2(OH)_2 \cdot 8H_2O$

Metavauxite was described by Gordon (1944) as being colorless, white, or pale greenish white. The acicular crystals are pale green when viewed on end. Individual crystals have a vitreous luster but fibrous aggregates are silky. The transparent to translucent crystals are brittle and rather soft (hardness of about 3). The crystals are striated parallel to the long dimension.

Metavauxite always occurs on wavellite, which encrusts brecciated fragments of porphyry along faults cutting the veins. It is commonly found intimately associated with paravauxite crystals, which in some cases are perched on needles of metavauxite, with the occasional rosette of blue vauxite crystals. One specimen of vauxite noted by Gordon (1944) has colorless, transparent crystals of paravauxite on one side, and white radial aggregates of metavauxite on the other.

Gordon (1944) noted acicular crystals to 2 cm in length, always aggregated into sub-parallel to radial aggregates. Bandy (1944) noted that metavauxite is relatively abundant as loose silky masses in open fractures along a branch of the San José vein, on Level 446. He reports that many years previous to 1944, pale green crystals up to 3 cm or more in length had been found on a branch of the San José vein on Level 411. In 1986 the Natural History Museum of Los Angeles County acquired a specimen with crystals to 5 cm, though its level of origin within the mine was not noted. In the early 1940's exceptional specimens were found along a branch of the Serrano vein above Level 355, associated with paravauxite and allophane. Open fissures were found coated with thin films of wavellite on which has been deposited (first) paravauxite and (second) metavauxite, both very loosely attached. Metavauxite alters quite readily to a brown to pale yellow, unidentified alteration product and is sometimes stained brown on the surface by iron oxides.

A few very nice specimens with crystals up to 3 cm were found

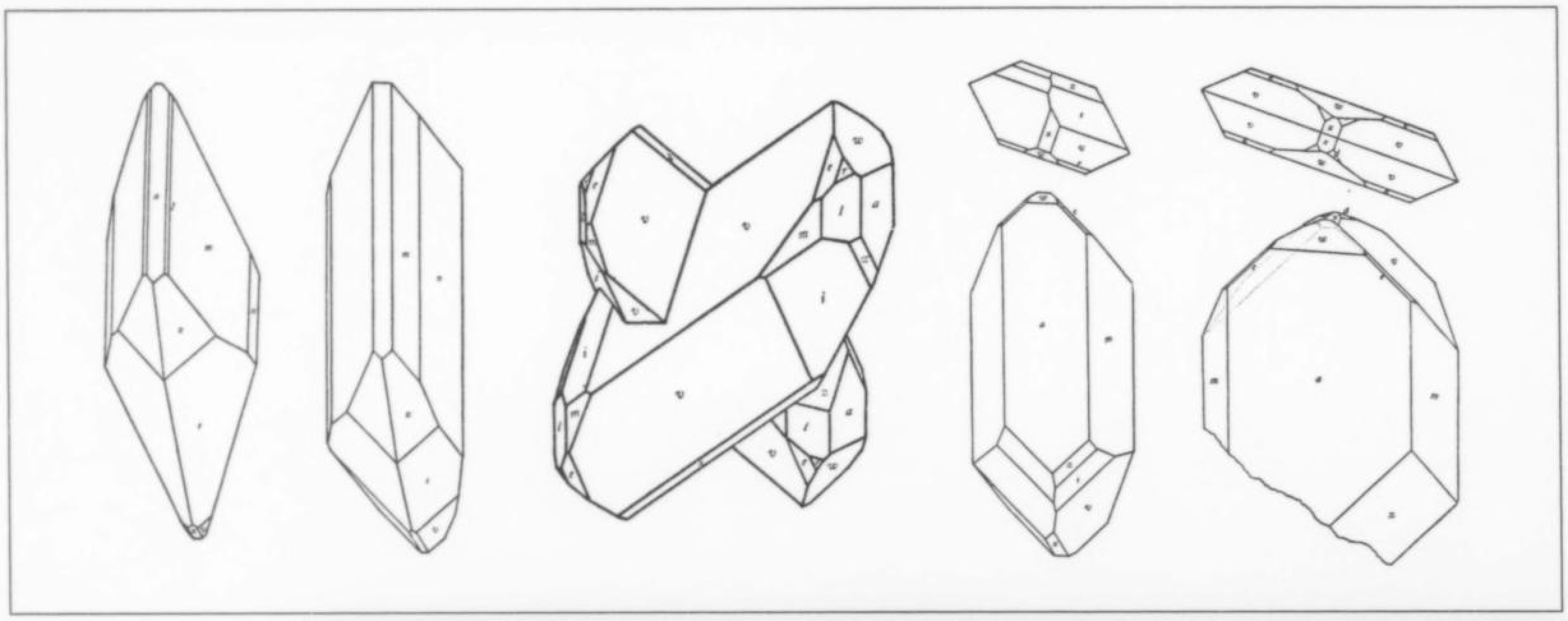


Figure 64. **Monazite from Llallagua; crystal drawings by Gordon (1944).**

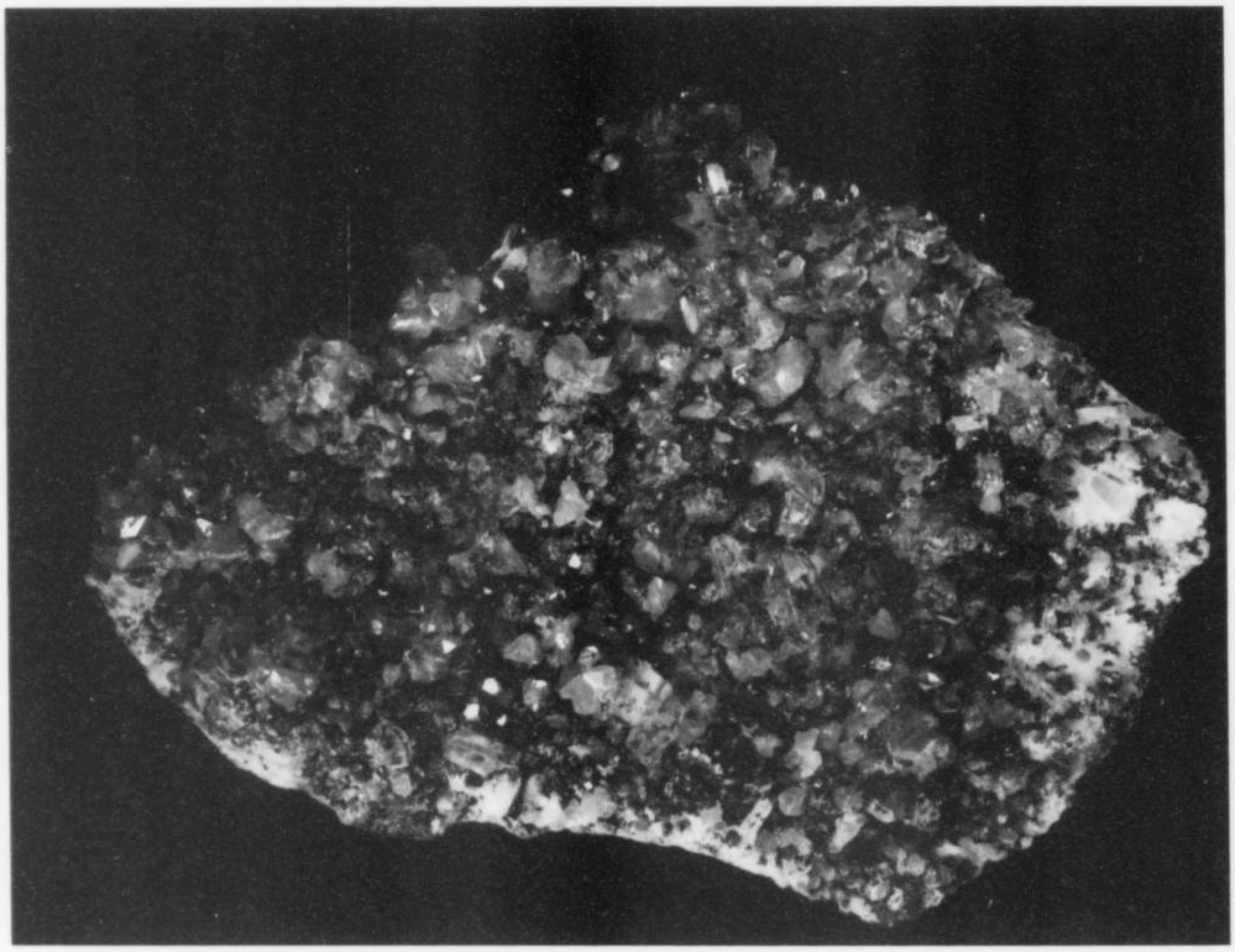


Figure 65. **Pinkish monazite twins on quartz and cassiterite, 9 cm across, from Llallagua. Bandy collection, now in the Natural History Museum of Los Angeles County; Anthony Kampf photo.**

in the summer of 2001; these specimens are among the best known for this species.

Miargyrite $AgSbS_2$

Miargyrite has been reported from Llallagua by Petrov *et al.* (2001), on the basis of information on specimen labels. However, the authors believe that the specimens in question are probably mislabeled as to locality, and confirmation of the source is lacking. Therefore the occurrence at Llallagua must be considered doubtful.

Monazite $(La,Ce,Y)PO_4$

Gordon (1944) provided an analysis of Llallagua monazite showing weight percentages of $La_2O_3 = 33.54$, $Ce_2O_3 = 31.74$, and $Y_2O_3 = 5.13$. This may not be as specific as it appears, because La and Ce values may actually refer to groups of elements rather than pure quantities. Small crystals of monazite are widespread in small quantities in all the veins. The largest reported crystals, found embedded in iron sulfides in the Bismarck vein, reach 2.5 cm (Bandy, 1944)! Llallagua monazite often appears pale pink in daylight and deeper pink under tungsten bulbs, but greenish gray to white under fluorescent lighting, an effect caused by a significant content of neodymium. Unlike monazite from other occurrences, Llallagua monazite is practically thorium-free, and therefore hardly radioactive at all; Gordon (1939) reported less than 10 ppm thorium. However, some monazite crystals from Llallagua do contain sufficient traces of thorium to produce an autoradiograph after a three-month exposure. Abundant grains and crude crystals of monazite to 1 cm, associated with white florencite-(Ce) crystals, quartz and pyrite, were found in 1999 in the Dolores Section stope.

Llallagua monazite crystals are typically prismatic, but exaggerrated development of the $\{\bar{2}11\}$ form can present a pyramidal aspect. Twinning is common, usually on (100), as contact twins and as penetration twins.

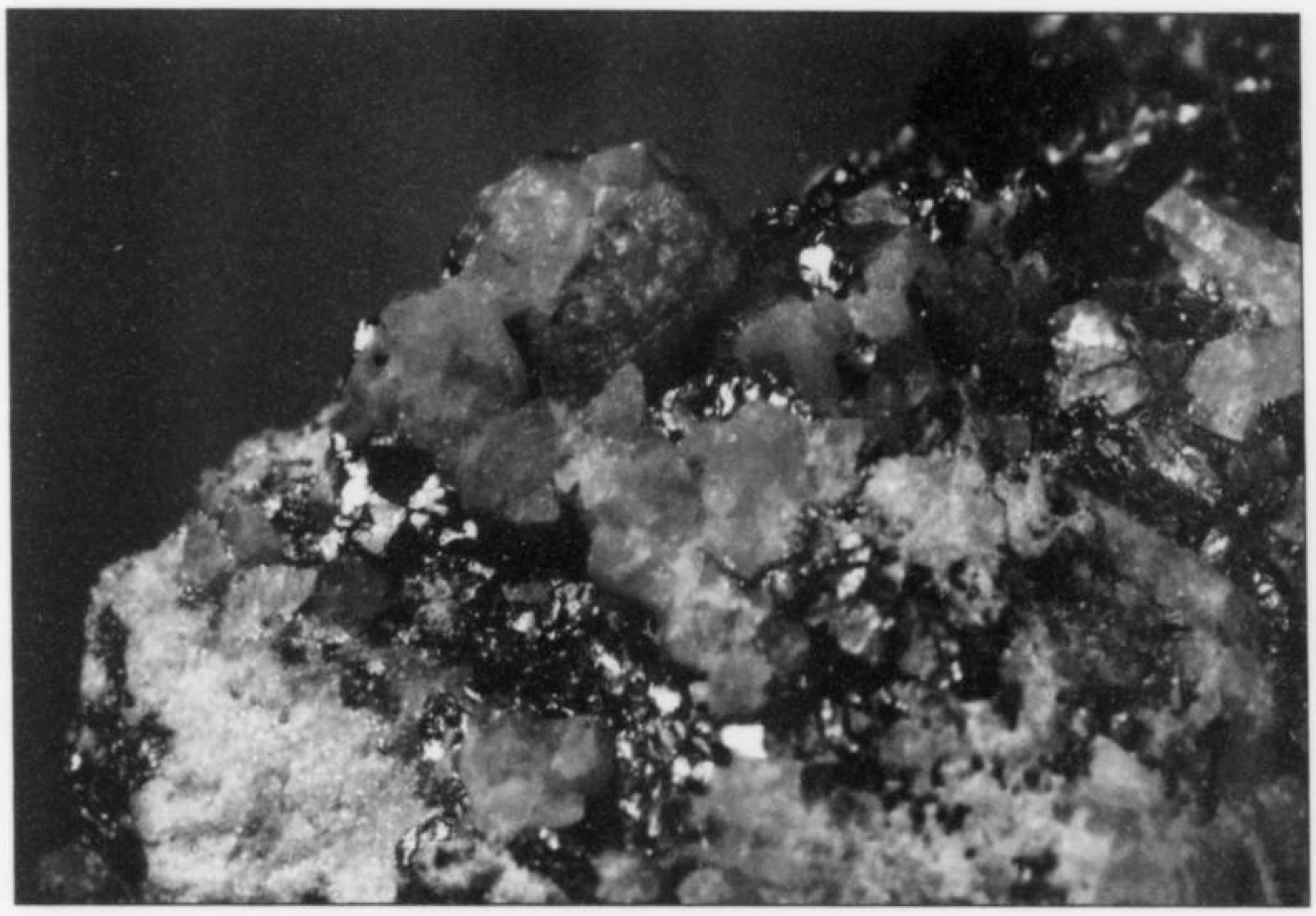


Figure 66. **Pinkish monazite crystals to 6 mm, with pyrite, from the Dolores section, Llallagua. Hyrsl collection and photo.**

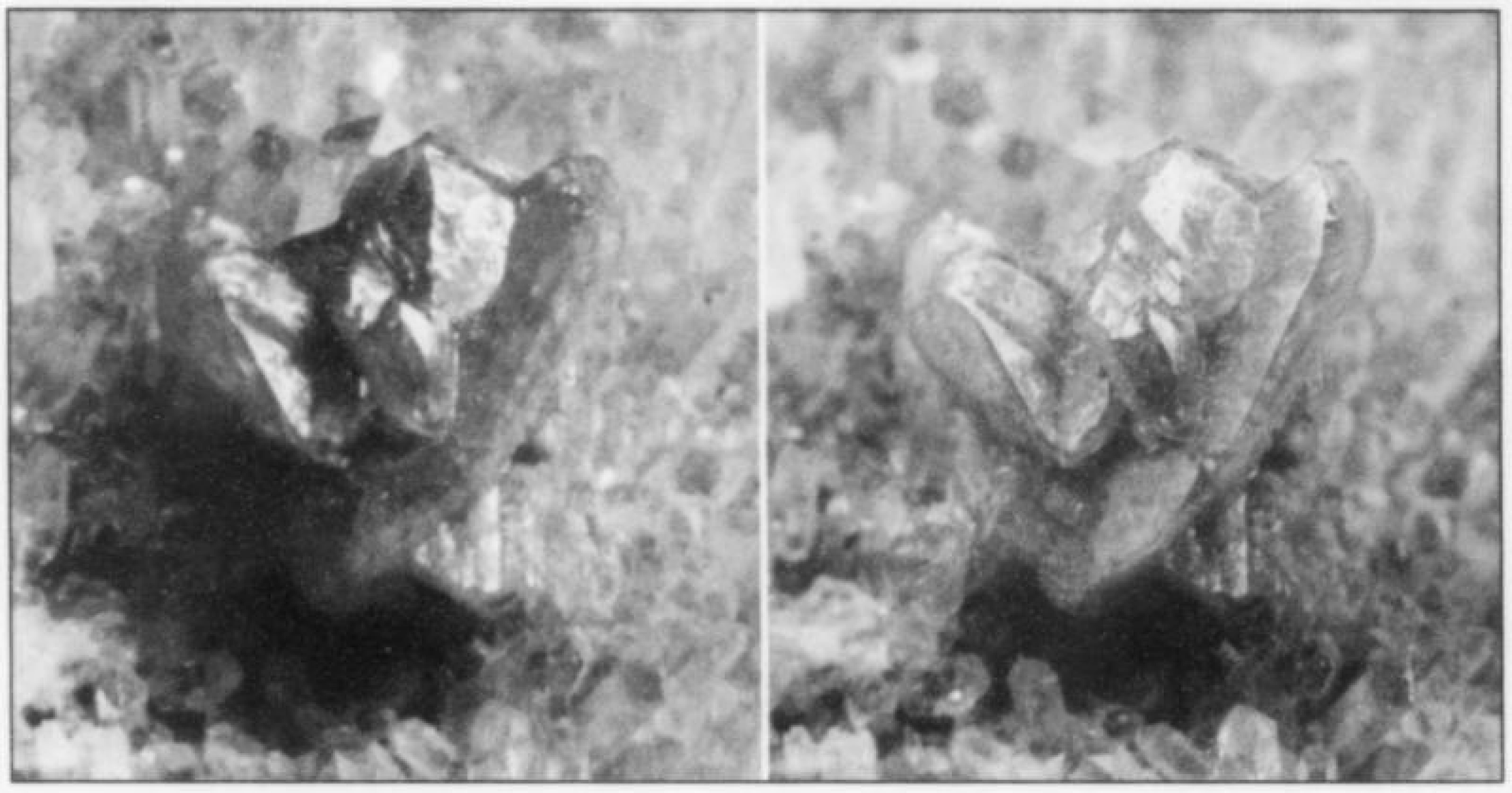


Figure 67. **Monazite crystal aggregate, 4 mm, from Llallagua, shown in fluorescent light (left) and tungsten light (right) to demonstrate the color change. Seaman Mineral Museum collection, Michigan Technological University; George Robinson and John Jaszczak photos.**

Monazite has been found as masses of crystals to 1 cm in the Salvadora vein; as twins on quartz crystals in the Bismarck vein; and abundantly in vugs in breccia in the Contacto vein. In some parageneses it appears to have formed in place of fluorapatite.

Bandy (1944) reported a rhombohedral dimorph of monazite which might be a new mineral, or which might be rhabdophane.

Ahlfeld (1955) mentions that the best monazite/rhabdophane crystal known was a 2-cm crystal in the collection of Pyotr Zubrzycki, a Polish mining engineer and Chief Geologist for COMIBOL, who had come to Bolivia as a refugee from stalinism. According to a story told to us by Dr. Fritz Berndt (*berndtite*), Zubrzycki panicked during the Bolivian revolution of 1952, mistakenly imagining that all the horrors of stalinist eastern Europe were about to be perpetrated on him again, and he ran away to Canada. Before escaping from Bolivia, he entrusted his fine Bolivian mineral collection to a humble miner, who buried it in the ground inside his earthen-floored hut, and nothing more has been heard of this collection since.

Muscovite $KAl_2AlSi_3O_{10}(OH)_2$

Fine-grained muscovite ("sericite") is the second most common mineral in the deposit, after quartz. It originated by massive sericitization of feldspars. Massive muscovite ("pinnite") forms pseudomorphs after cordierite crystals in granodiorite pegmatites. Red micaceous crystals and aggregates found recently on a dump, filling fissures in narrow quartz-cassiterite veins, have been analyzed as muscovite.

Nacrite $Al_2Si_2O_5(OH)_4$

Nacrite (the monoclinic polymorph of kaolinite and halloysite) was tentatively identified in vugs by Mark Bandy (1944) as white hexagonal-tabular microcrystals with pearly luster, especially in younger veins. It can still be found on some cassiterite and quartz specimens, often with monazite-(Ce), and as radiating spheres on franckeite.

Natanite $Fe^{2+}Sn^{4+}(OH)_6$

Natanite occurs extremely rarely as pale yellow, translucent, sharp simple octahedrons to 0.2 mm on quartz and pyrite from the Dolores Atras Section. Gordon (1944) figured a brown, isotropic, octahedral crystal of an unknown species, probably natanite (he cited an index of refraction of 1.745; natanite equals 1.755), with epitactic overgrowths of an unknown tetragonal mineral along the octahedron edges, possibly jeanbandyite (q.v.).

Opal $SiO_2 \cdot nH_2O$

Opal formed by hot springs is known from several sinter deposits around the stock, for example at Uncia. Greene (1943) reported opal pseudomorphs after quartz crystals at Llallagua.

Orpiment As_2S_3

Orange-yellow orpiment coating quartz was described by Gordon (1944). It originated from weathered arsenopyrite.

Paravauxite $FeAl_2(PO_4)_2(OH)_2 \cdot 8H_2O$

Paravauxite was described by Gordon (1923), along with vauxite.

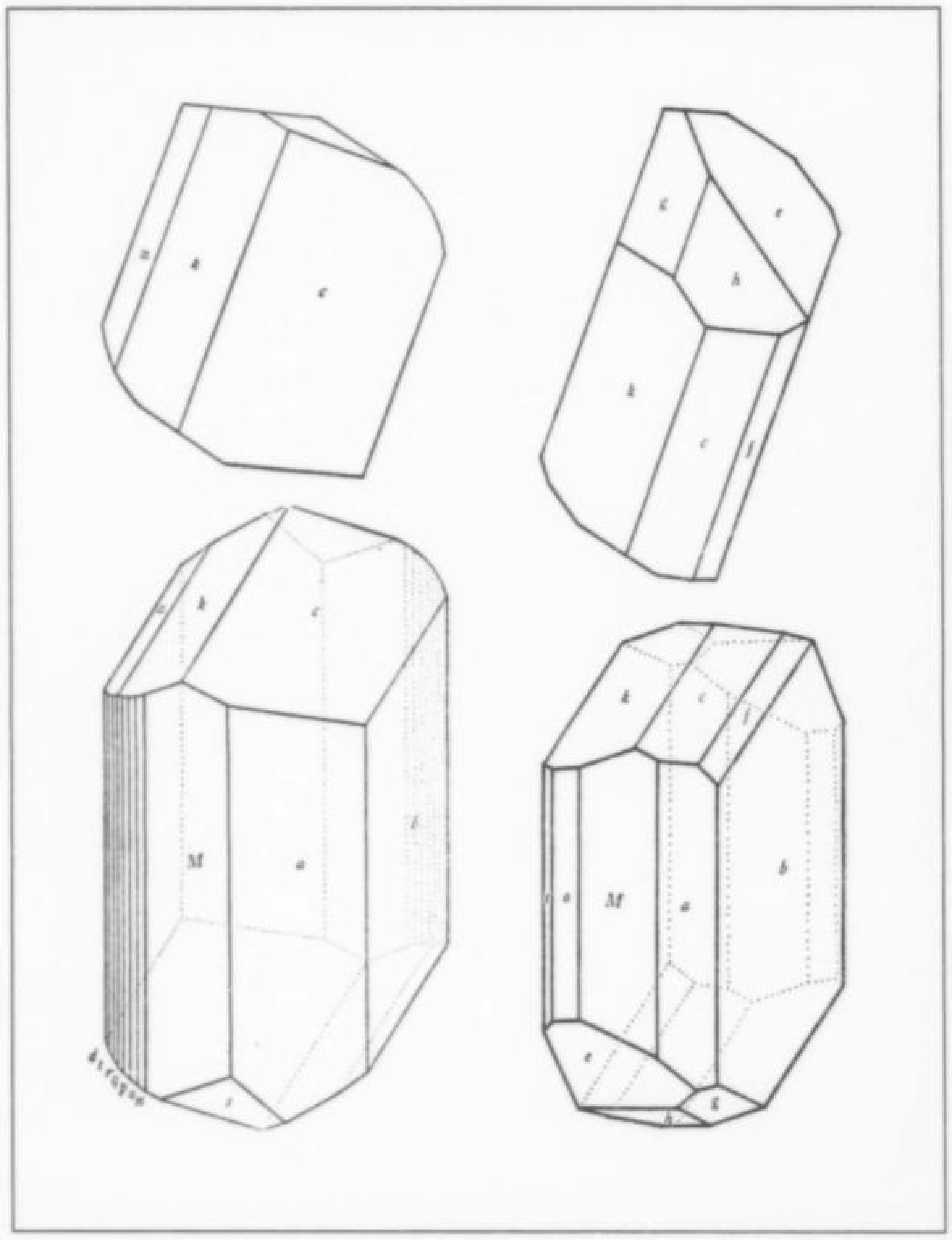


Figure 68. **Paravauxite from Llallagua; crystal drawings by Gordon (1944).**

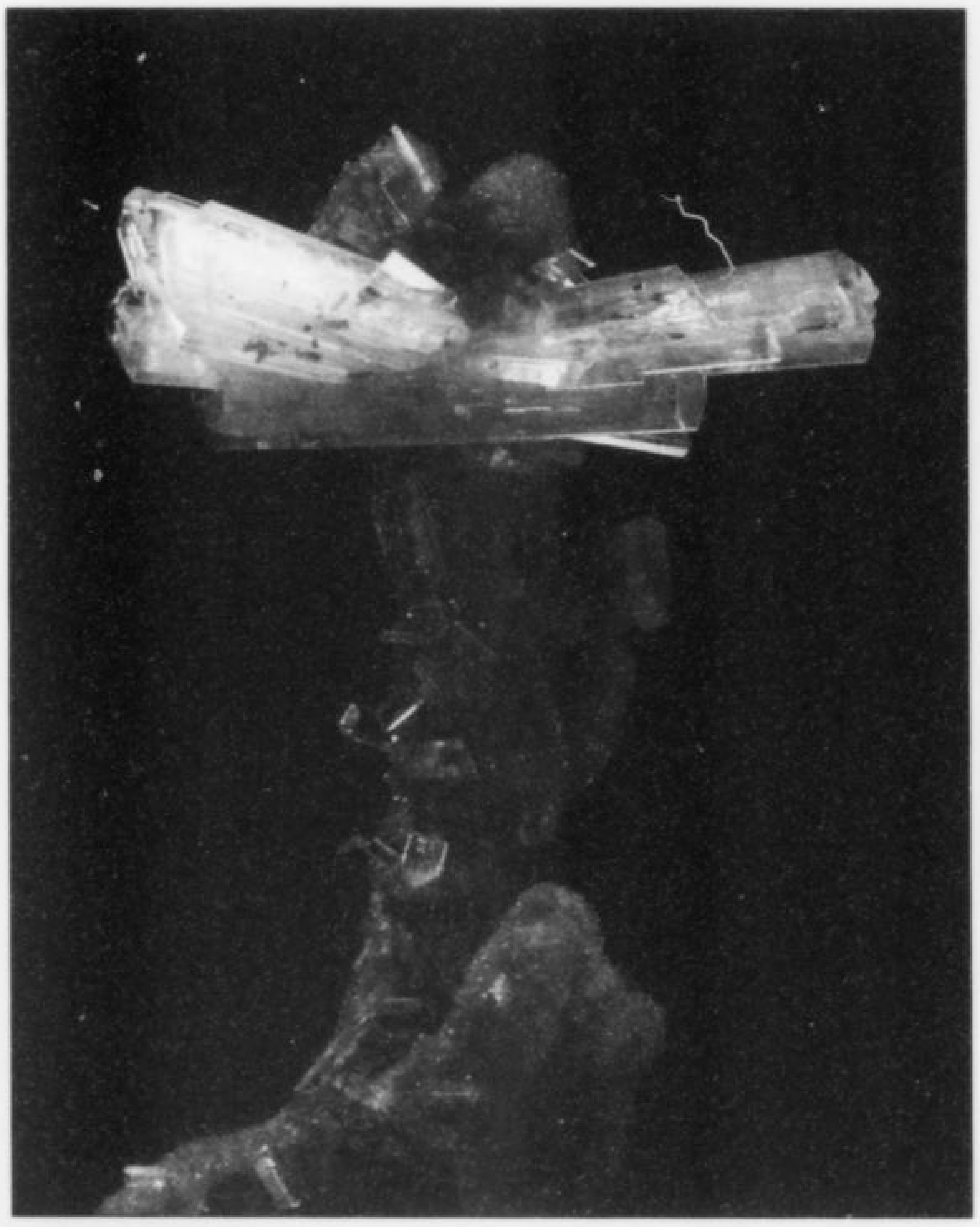


Figure 69. **Paravauxite crystals, 2.3 cm, perched on wavellite, from Llallagua. Jeff Scovil photo; Jim and Dawn Minette collection.**

Figure 70. **Paravauxite crystal cluster, 2.8 cm, from Llallagua. Sharon and Eugene Cisneros collection; Rock Currier photo.**

It is the most common of the three "vauxites" (the other being metavauxite) and sometimes forms large masses of crystals in vugs. The characteristic brittle, vitreous, transparent to translucent triclinic crystals are pale green when large and colorless when small. The crystal habit resembles that of gypsum, in individual crystals to 1 × 2 cm which are prismatic to tabular on (010), with perfect cleavage parallel to (010). Paravauxite almost always occurs as individual crystals perched on wavellite encrusting quartz in the tin veins and porphyry breccia fragments in the fault zones. It has been found on crusts of blue vauxite in the fault zones, and as crystals perched on metavauxite needles. Childrenite has often been observed in association with paravauxite on wavellite. Although radial to subparallel aggregates are known, paravauxite shows much less tendency toward radial aggregation than vauxite

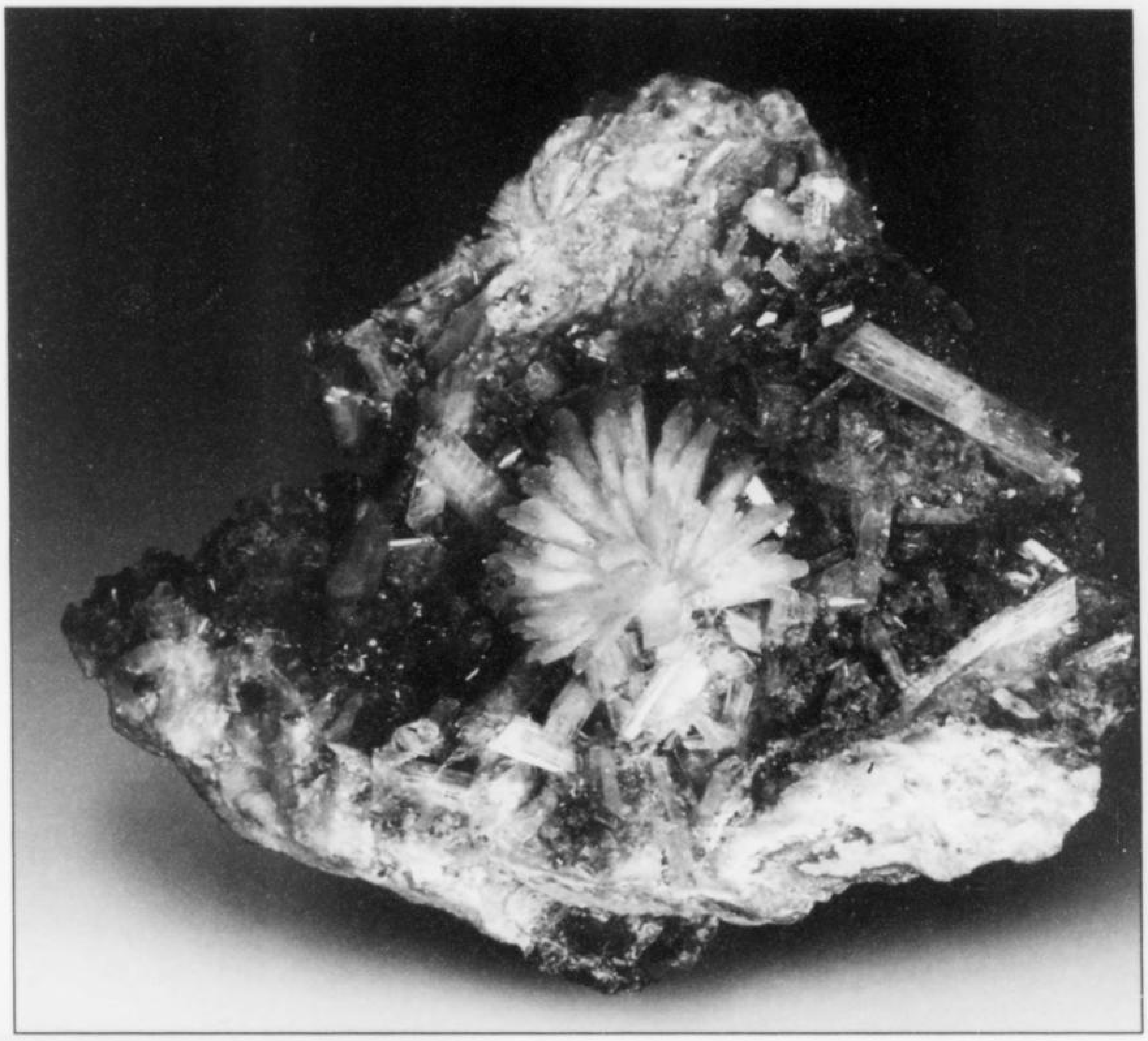


Figure 71. **Paravauxite crystal spray on matrix, perhaps the finest known, 8 cm across, from Llallagua. Bandy collection; current owner unknown (probably still in the possession of the Bandy family); Wolfgang Mueller photo.**

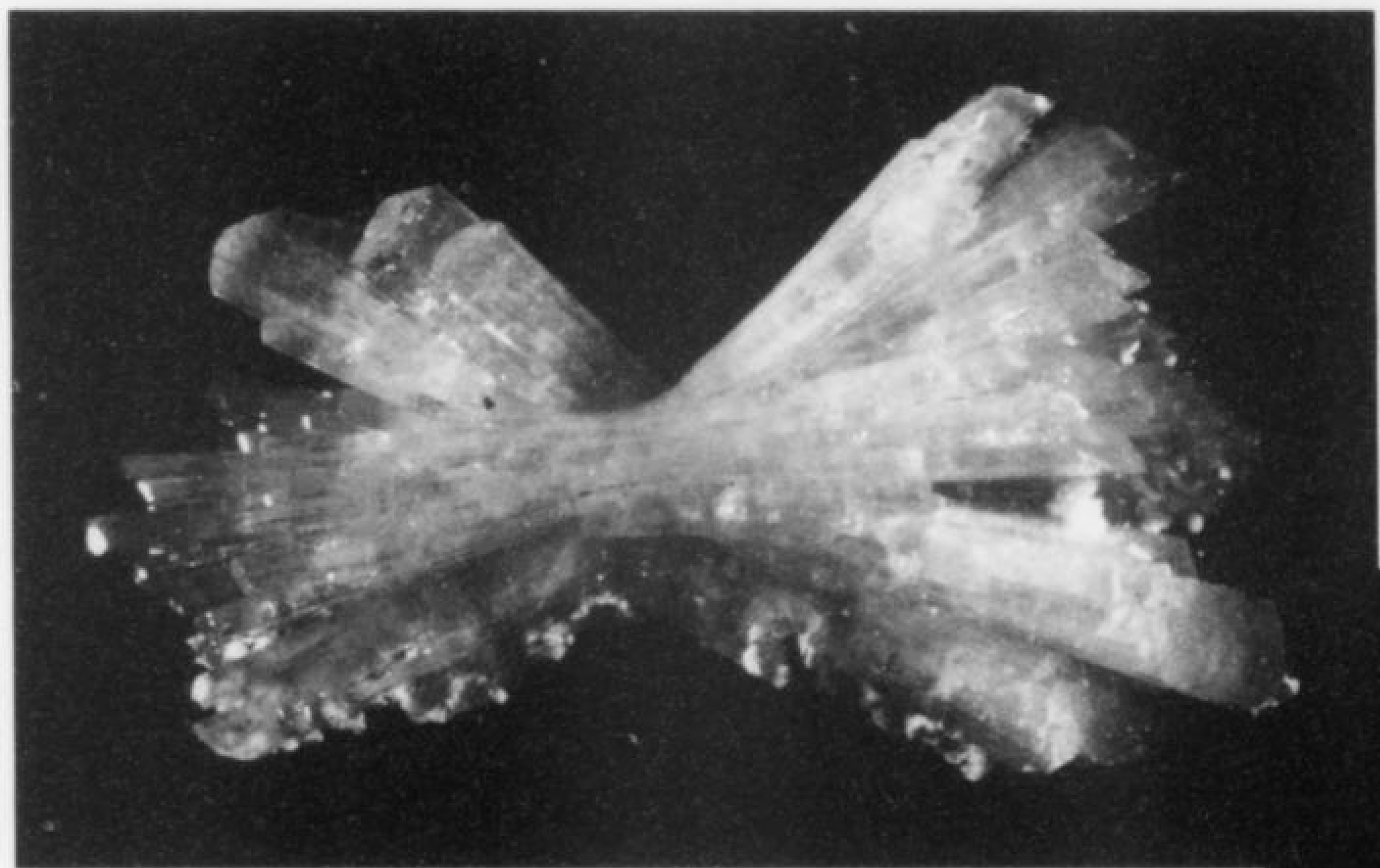


Figure 72. **Paravauxite "bow tie," 2.6 cm, from Llallagua. Sharon and Eugene Cisneros collection; Rock Currier photo.**

or metavauxite (Gordon, 1944). Surface oxidation can turn the crystals pale yellow. White opaque crystals have been shown to be pseudomorphs of sigloite after paravauxite.

Bandy (1944) reported that fine, colorless crystals of paravauxite coating wavellite had been found in the stock, 70 meters from the contact, along the San José vein on Level 650. But the finest specimens from the early 1940's were found in vugs along the Contacto vein in the sediments on Level 411, 400 meters from the contact. These vugs were lined with wavellite on which had grown paravauxite crystals and later childrenite, which preferentially coated the exposed wavellite. Greenish paravauxite crystals were also found in vugs in wavellite. On Level 516 in the Contacto vein, about 550 meters from the contact, Bandy (1944) reports a similar

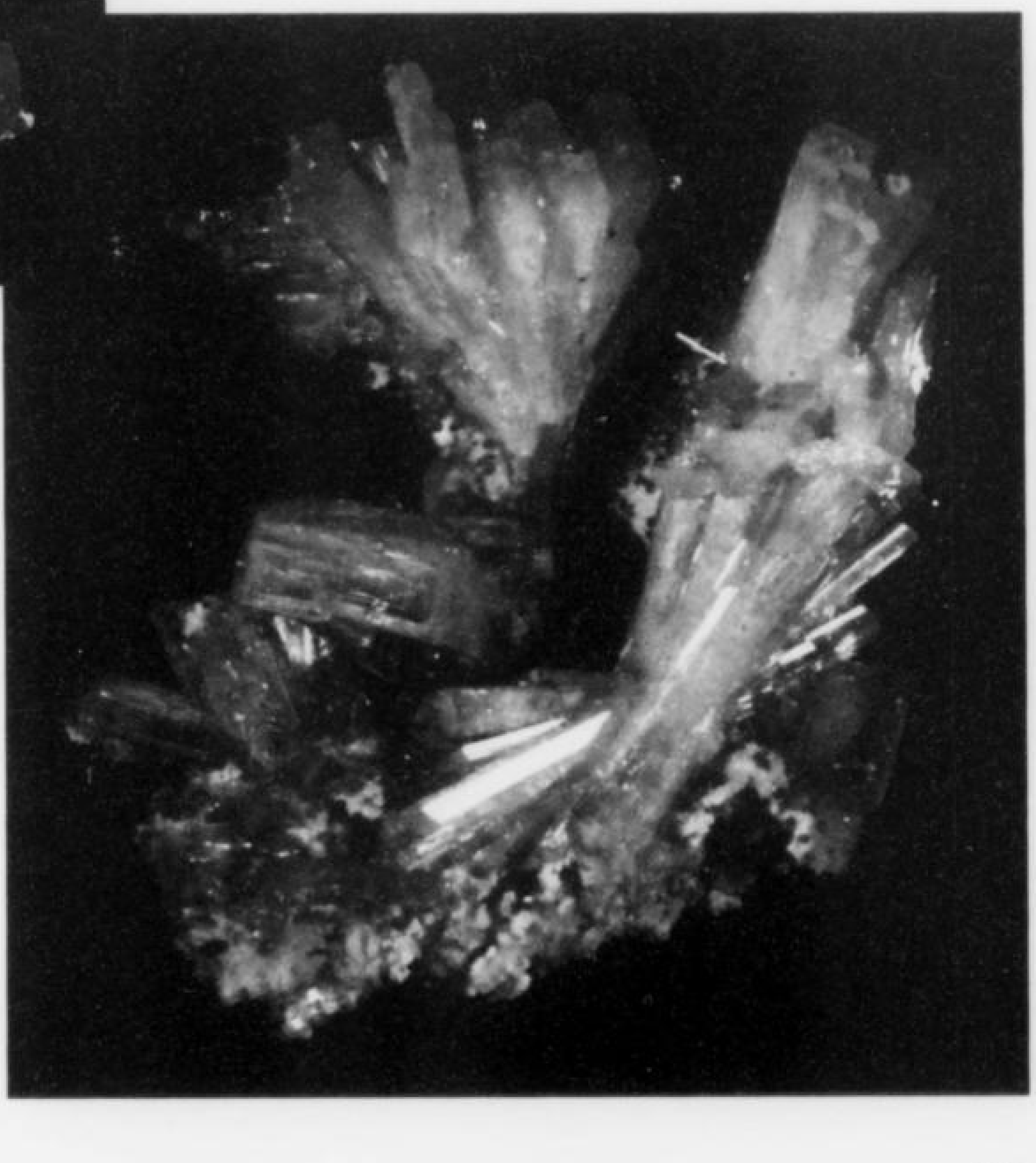


Figure 73. **Paravauxite crystal cluster, 2.7 cm, from Llallagua. Sharon and Eugene Cisneros collection; Rock Currier photo.**

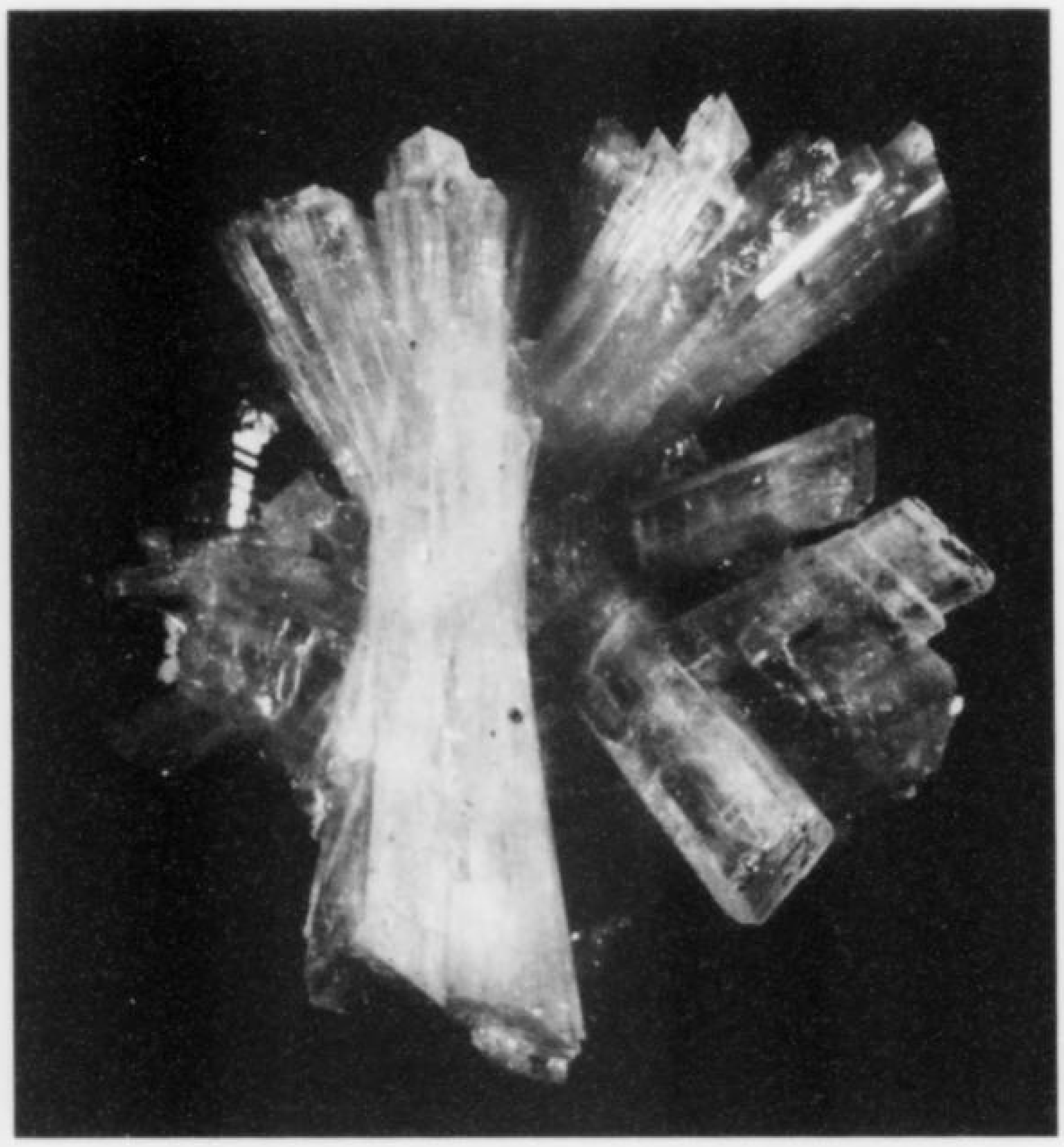


Figure 74. **Paravauxite crystal cluster, 2.4 cm, from Llallagua. Sharon and Eugene Cisneros collection; Rock Currier photo.**

Figure 75. **Paravauxite crystal cluster, 3.7 cm, from Llallagua. Jeff Scovil photo; Alfredo Petrov collection.**

occurrence of paravauxite except that it had been coated by childrenite and then had dissolved away, leaving childrenite shells. In the 1930's crystals to 3 cm were found on Level 411, along a branch of the Serrano or San José vein, and the mineral was common as greenish crystals on allophane along the Bismarck vein near the contact on the same level.

There have been several recent, fairly abundant discoveries of paravauxite, with some specimens showing splendid pale green crystals to 3 cm.

Pickeringite $MgAl_2(SO_4)_4 \cdot 22H_2O$

Pickeringite was identified by Bandy (1944) as a post-mining formation in old galleries, together with halotrichite.

Plumbogummite $PbAl_3(PO_4)_2(OH,H_2O)_6$

Specimens showing pale yellow mammillary or microbotryoidal crusts of plumbogummite on drusy quartz and cassiterite in fissures are found fairly commonly on some dumps. The authors have found somewhat more interesting specimens in which plumbogummite forms orange shells around crude octahedral jeanbandyite crystals.

Potosíite $Pb_6Sn_2^{4+}Fe^{2+}Sb_2^{5+}S_{16}$

Potosíite has been reported from Llallagua (www.mindat.org), as being unconfirmed and therefore doubtful.

Pyrargyrite Ag_3SbS_3

Pyrargyrite probably does not occur in the Llallagua stock, but it was an ore mineral with galena in a peripheral vein in graywackes at Uncia, 3 km south of the intrusion.

Pyrite FeS_2

Pyrite is very common as beautiful, sharp, octahedral, cubic or cuboctahedral crystals (but never as pyritohedrons). It appears also

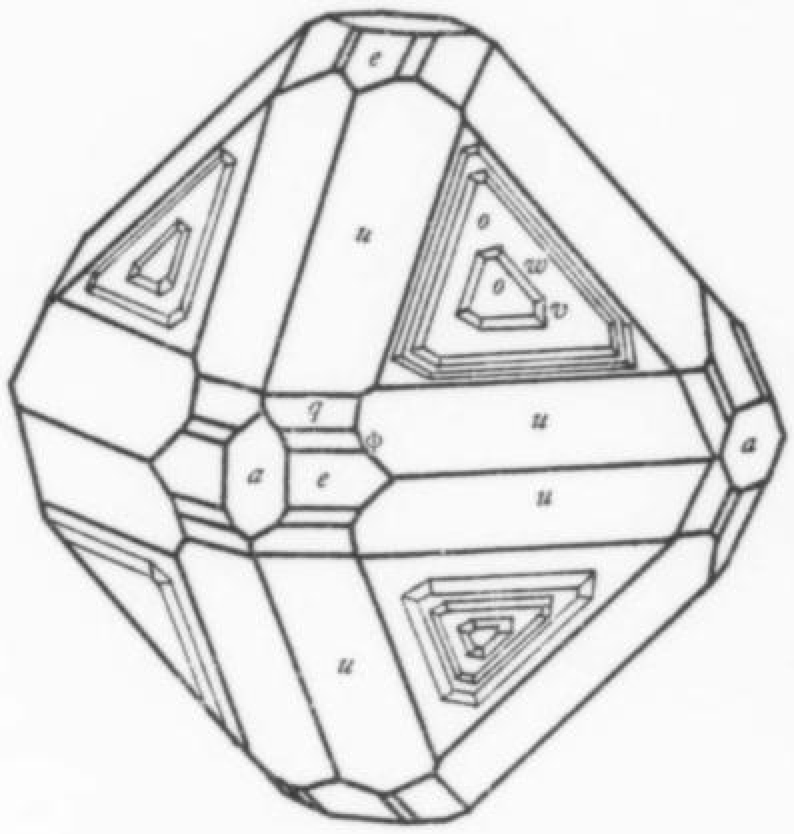


Figure 76. **Pyrite from Llallagua; crystal drawing by Gordon (1944).**

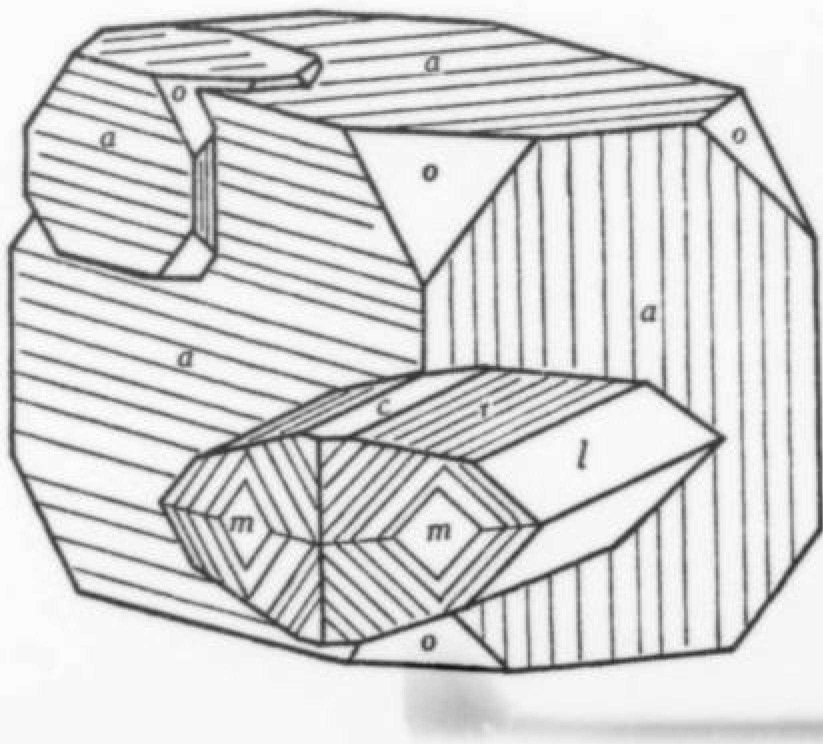
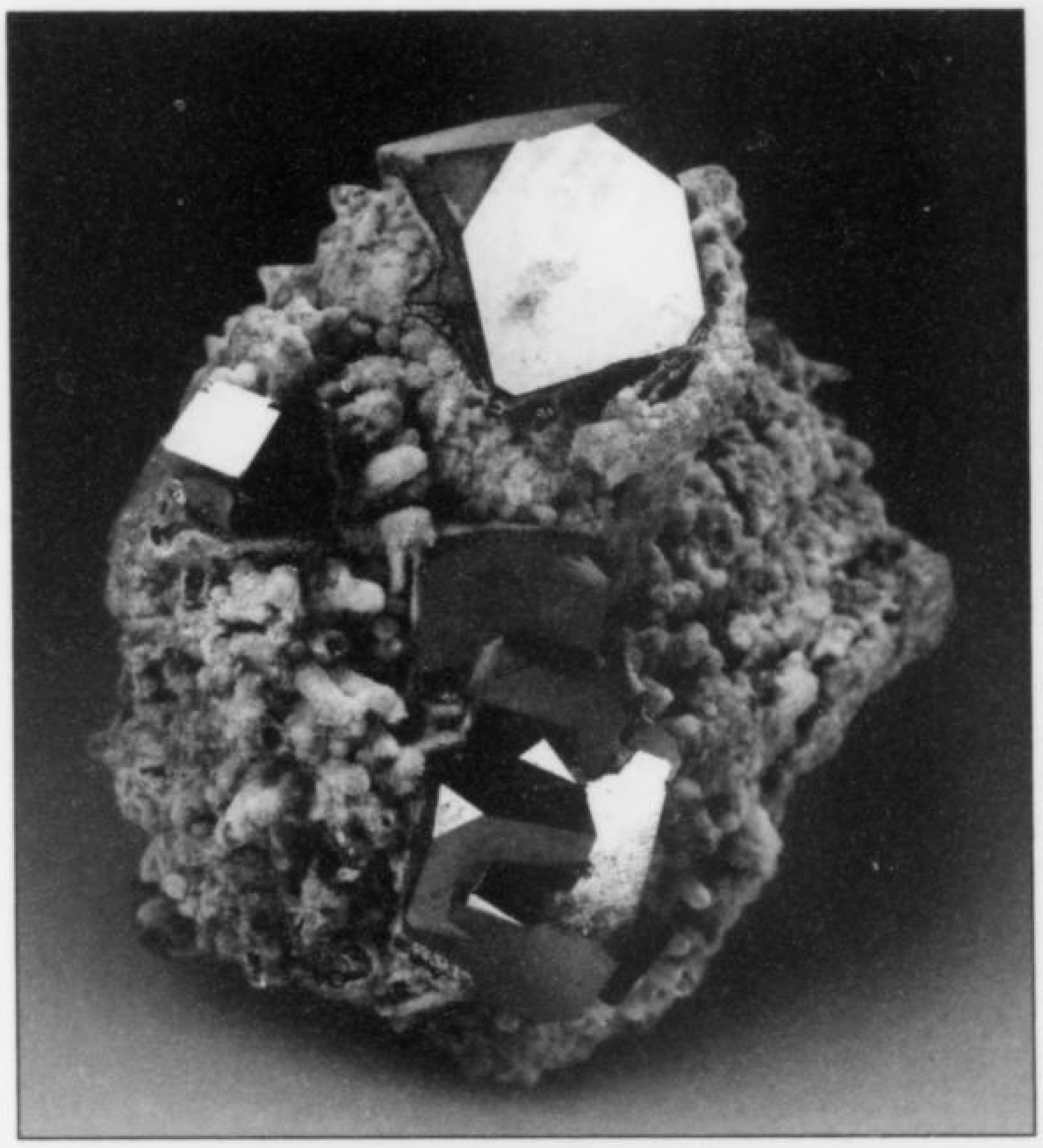


Figure 77. **Pyrite with attached marcasite from Llallagua; crystal drawing by Gordon (1944).**

Figure 78. **Pyrite crystals on wavellite coated sphalerite crystals, 4.5 cm, from the Plata vein, Level 190, Llallagua. Seaman Mineral Museum collection, Michigan Technological University; George Robinson photo.**



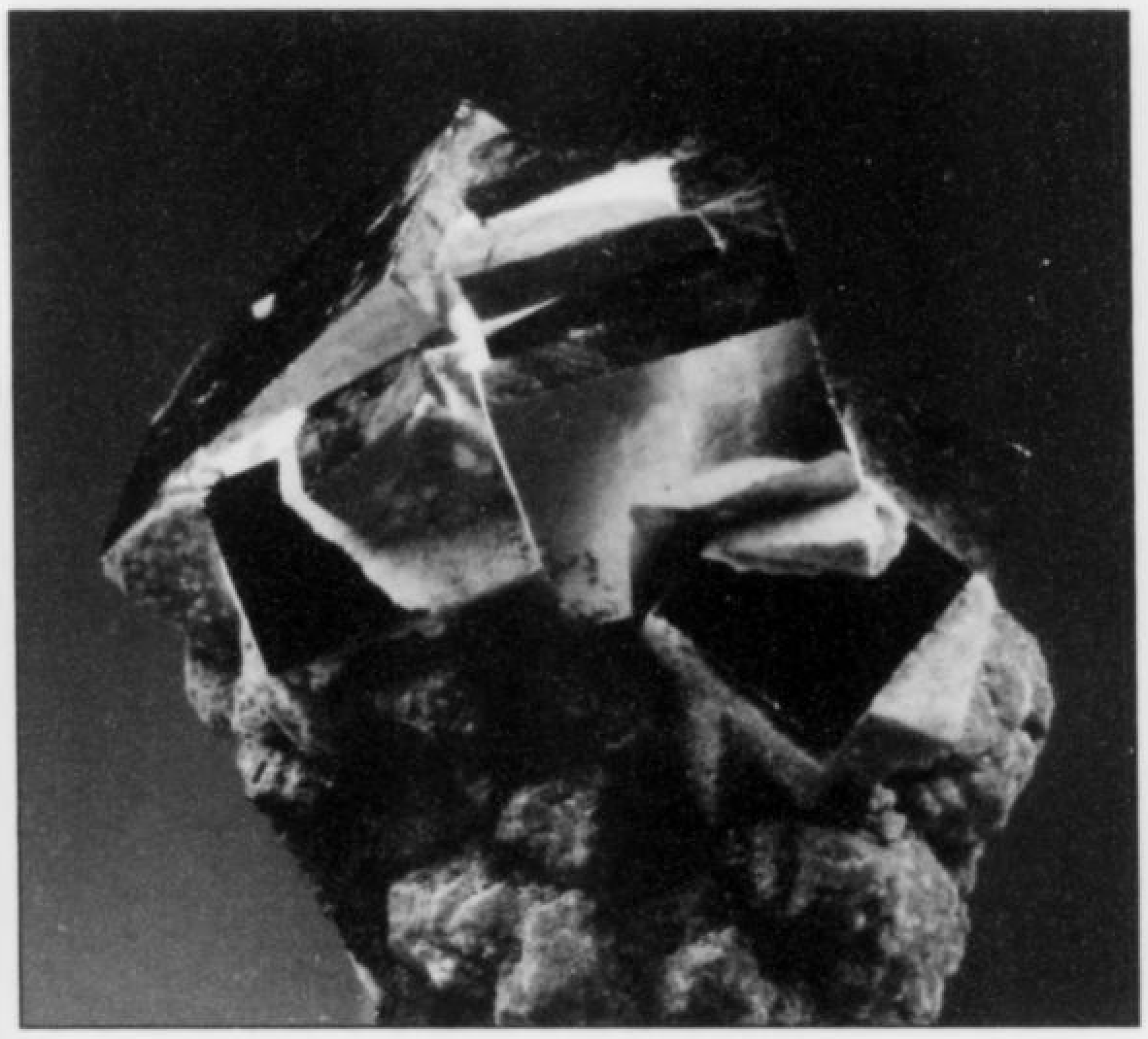


Figure 79. **Pyrite crystals on wavellite and quartz, 6.4 cm, from Llallagua. Bandy collection, Natural History Museum of Los Angeles County; Anthony Kampf photo.**

Figure 80. **Franckeite and pyrite after pyrrhotite, 5 cm, from Llallagua. Bandy collection, Natural History Museum of Los Angeles County; Wolfgang Mueller photo.**

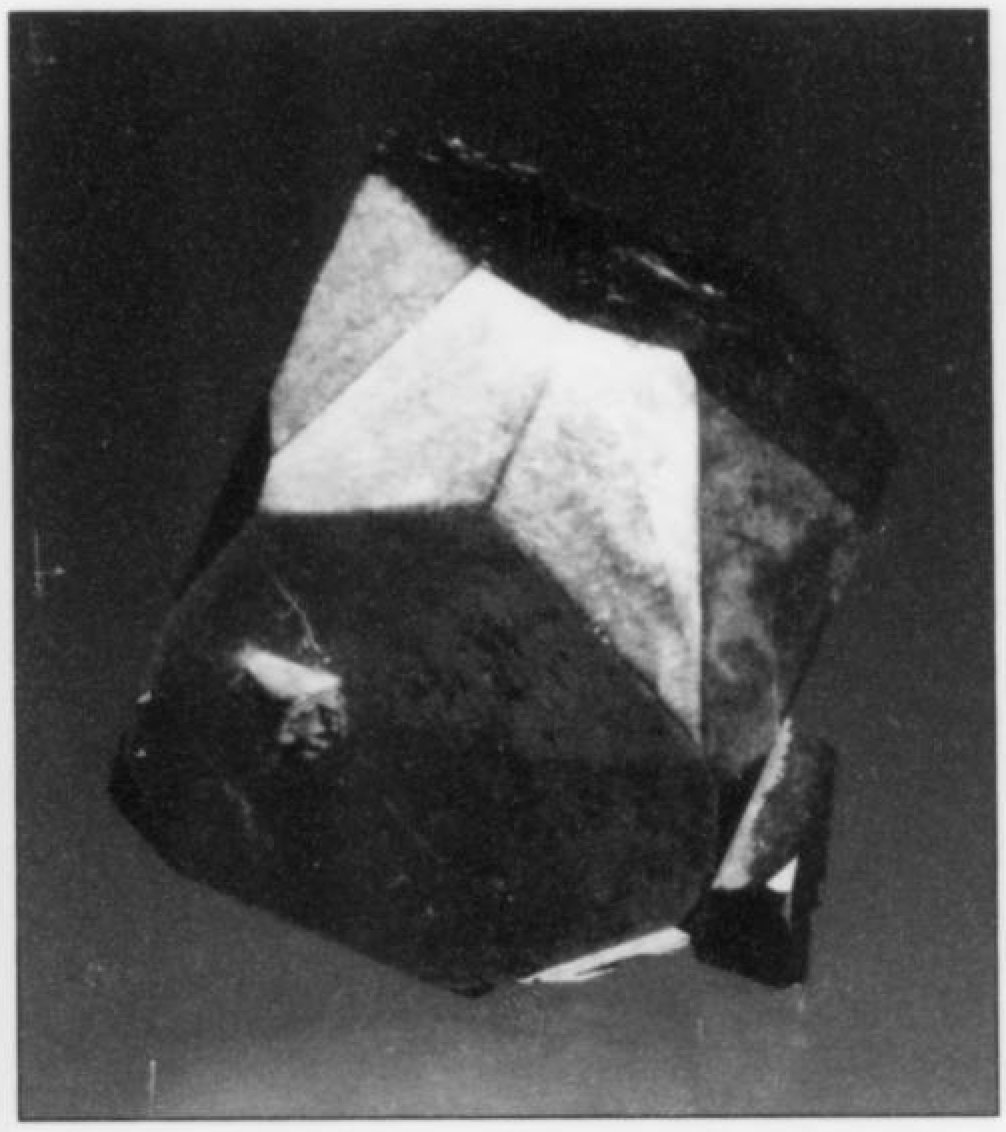


Figure 81. **Pyrite crystal, 3 cm, from Llallagua. Seaman Mineral Museum collection, Michigan Technological University; George Robinson photo.**

as pseudomorphs after pyrrhotite and, rarely, after teallite and feldspar. Pyrite crystals from some weathered dumps exhibit peculiar tunnels or serpentine "worm holes" etched into them; the finest specimens of this kind were found around the periphery of the main mineralization zone. Nice pyrite crystals to 7 cm were found recently as floaters embedded in soft, massive franckeite in the Dolores Section stope.

Pyromorphite $Pb_5(PO_4)_3Cl$

Green pyromorphite crystals were found in an oxidized vein 1.7 km east of the southern end of the stock (Bandy, 1944).

Figure 82. **A cluster of Japan-law quartz twins, 8 cm, from Llallagua. Hyrsl collection and photo.**

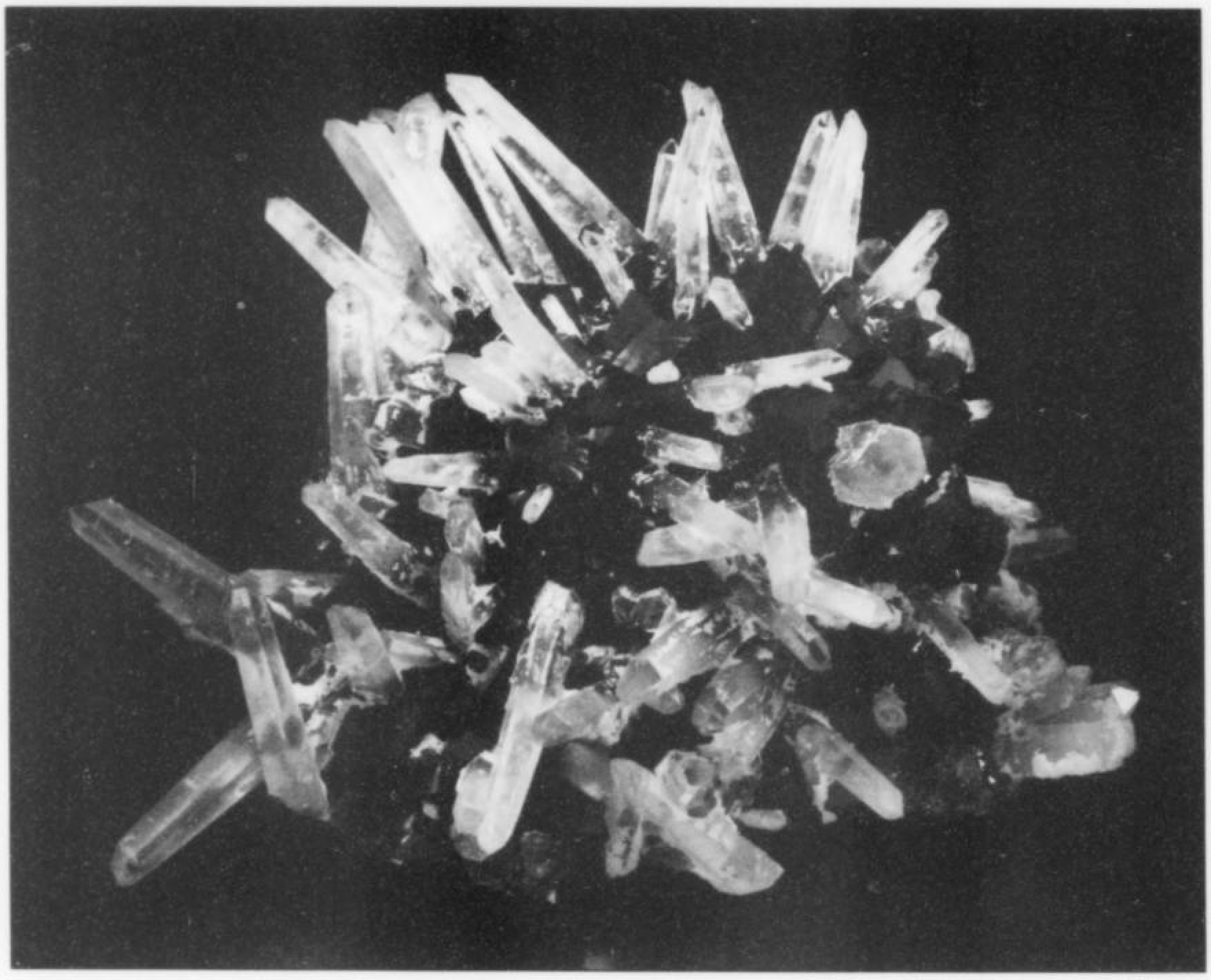


Figure 83. **Quartz crystals on cassiterite, 11 cm, from the San José vein, Llallagua. Bandy collection, Natural History Museum of Los Angeles County; Larry Reynolds photo.**

Pyrrhotite $Fe_{1-x}S$

Pyrrhotite was widespread as hexagonal, tabular to barrel-shaped prismatic crystals, but almost all of the original pyrrhotite has been replaced by pyrite and marcasite. Pseudomorphic crystals can reach 15 cm, and some are covered by a wavellite crust. Bandy (1944) mentioned a portion of the Contacto vein on Level 516 where unaltered pyrrhotite formed masses 2 meters across.

Quartz SiO_2

Quartz is the most common mineral at Llallagua, in crystals reaching 10 cm in length. Many of the quartz specimens are encrusted by wavellite. Flattened Japan-law twins are frequently found in the centers of veins. Transparent quartz crystals commonly show tiny inclusions of metallic minerals such as arsenopyrite or pyrrhotite, and occasionally wolframite; Bandy (1944) described cassiterite crystals and tourmaline embedded in quartz. Yellow-orange inclusions of monazite or xenotime up to about 2 mm are very rare. One metallic acicular crystal included in quartz was determined by X-ray diffraction and X-ray fluorescence analysis to be a mineral close to gustavite ($PbAgBi_3S_6$).

Realgar AsS

Acicular microcrystals of realgar are occasionally seen coating arsenopyrite; one mass of native arsenic and gypsum shows lamellae of realgar. The species is thought also to constitute the coloring matter in Llallagua's pink sphalerite.

Rhabdophane? $(La,Ce,Y)PO_4\cdot H_2O$

Bandy (1944) cited an undescribed species which he thought to be a rhombohedral analog of monazite; he suggested it should be named "llallagualite." It was found in vugs along the Plata vein on Level 190, in crystals to 3 mm showing the base and two rhombohedrons. Unfortunately it has never been confirmed as a new species (thereby precluding the formal naming of any other new species in honor of this famous locality), and Bandy's specimens of it cannot be found. Clark (1993) suggested that the mineral may be rhabdophane.

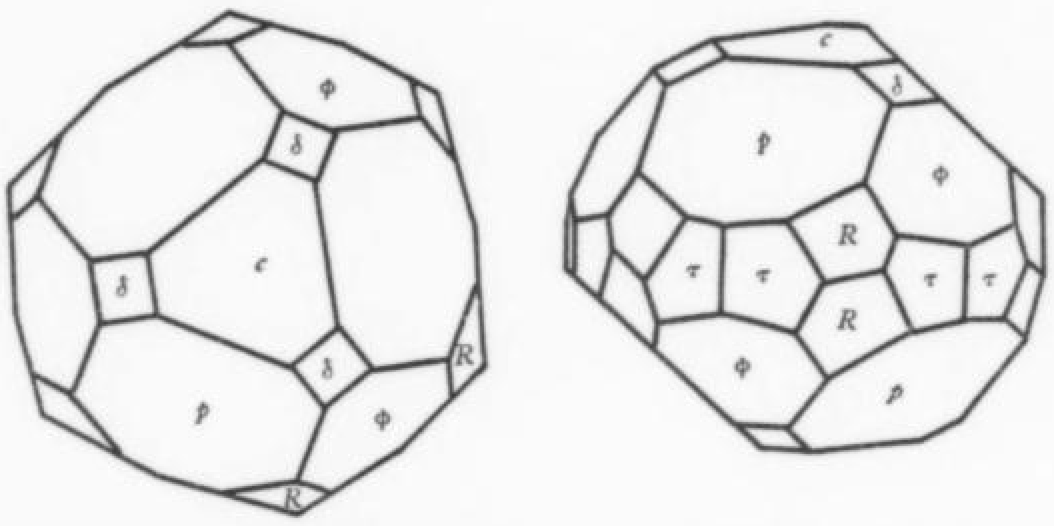


Figure 84. **Rhodochrosite from Llallagua; crystal drawings by Gordon (1944).**

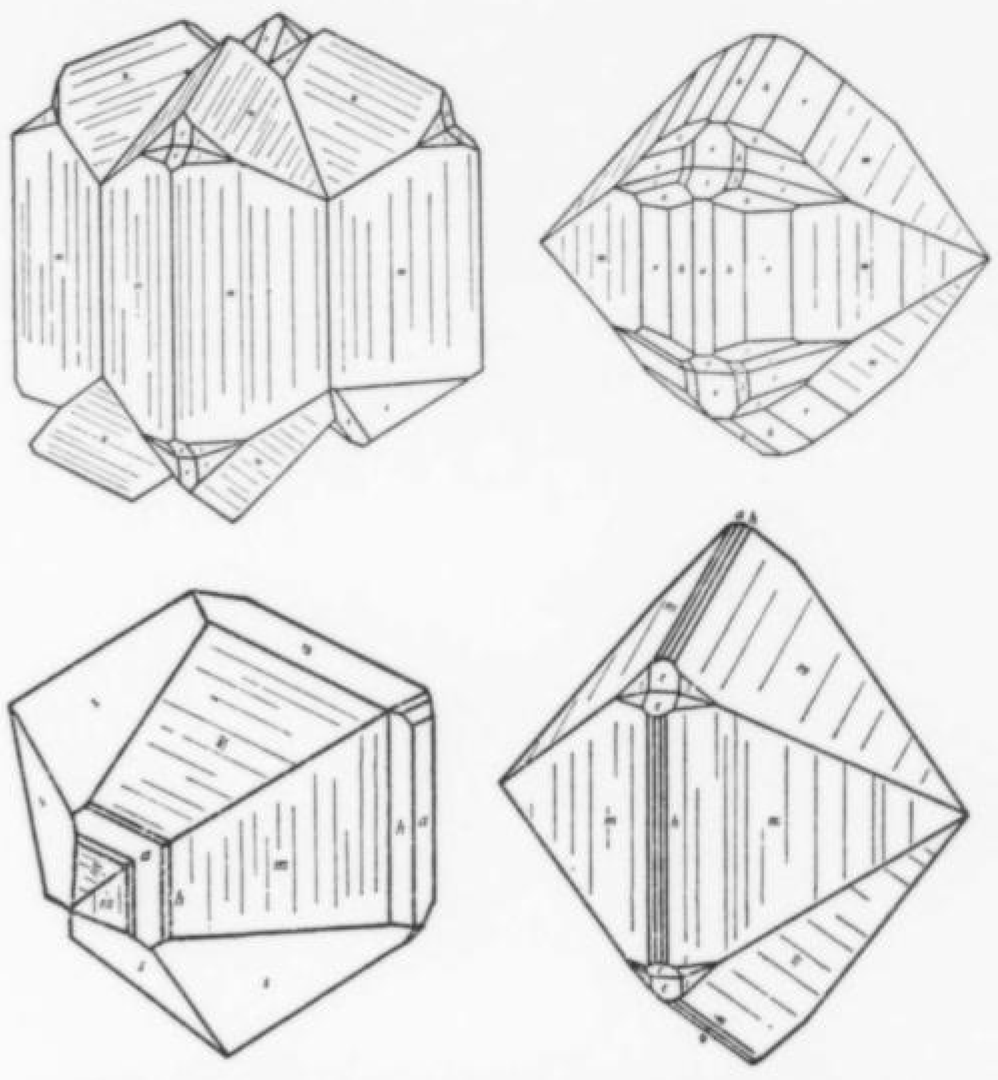


Figure 86. **Rutile (cyclic twins) from Llallagua; crystal drawings by Gordon (1944).**

Rhodochrosite $MnCO_3$

Llallagua is the only Bolivian locality which has yielded good rhodochrosite crystals. The attractive pink rhombohedrons, to 1 cm, are found rarely in vugs with wurtzite and sphalerite. Gordon (1944) depicts equant crystals whose complex faces lend them an almost rounded habit; the faces include {0001}, {$11\bar{2}1$}, {$\bar{1}\bar{1}22$}, {$81\bar{9}1$}, {$\bar{2}\bar{2}41$} and {$32\bar{5}0$}. Rhodochrosite also occurs as veinlets in masses of iron sulfides. Some Llallagua rhodochrosite is pale brown rather than pink, and so is difficult to distinguish from siderite.

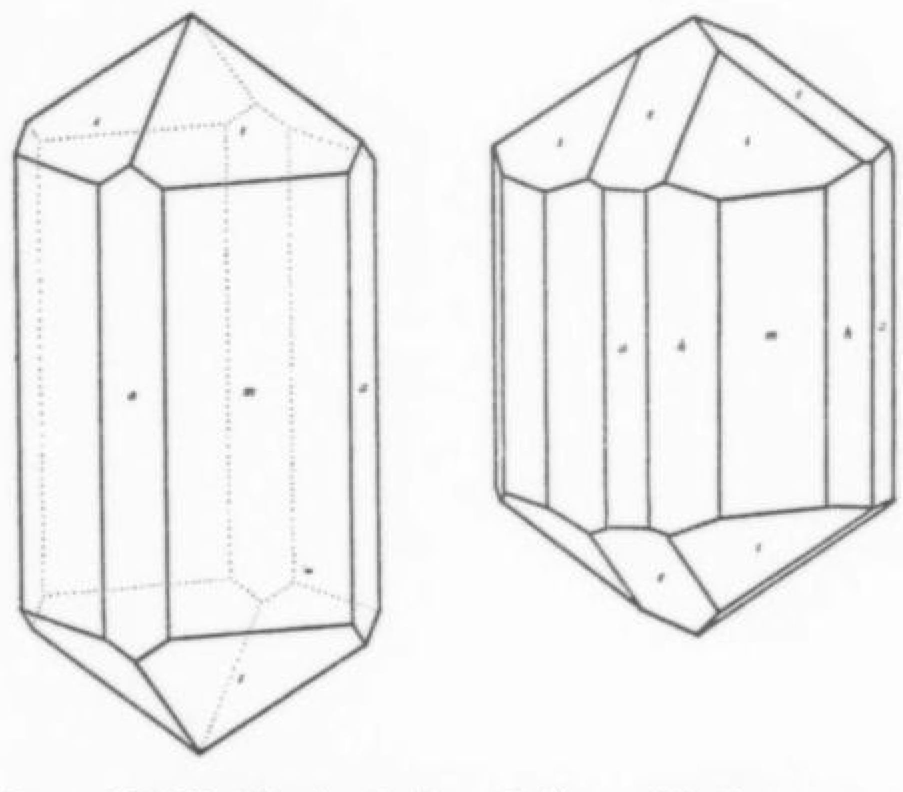


Figure 85. **Rutile (untwinned) from Llallagua; crystal drawings by Gordon (1944).**

Römerite $Fe^{2+}Fe^{3+}_2(SO_4)_4\cdot 14H_2O$

Ahlfeld and Muños Reyes (1955) reported römerite as crusts of rust-brown crystals in old workings, associated with chalcanthite, melanterite and pickeringite.

Rutile TiO_2

Tiny crystal grains of rutile are common in the igneous rocks as well as in surrounding sediments. Some of the rutile might be of hydrothermal origin, according to Turneaure (1935). It also occurs as tiny (0.5 mm) black to brown crystals in cavities in muscovite; the prismatic crystals are easily mistaken for cassiterite. Geniculated and reticulated twins are common.

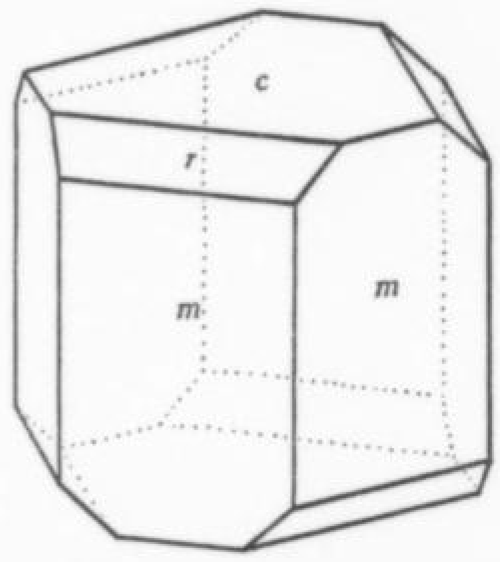


Figure 87. **Siderite from Llallagua; crystal drawing by Gordon (1944).**

Scheelite $CaWO_4$

Tiny orange, bipyramidal scheelite crystals were identified by Gordon (1944) on one specimen from Level 435 of the San José vein.

Siderite $FeCO_3$

As in most Bolivian mines, siderite at Llallagua is by far the most abundant carbonate gangue mineral, especially in younger veins and on the periphery of the deposit (although crystals are much less common here than in other Bolivian tin mines). Nice rhombohedral crystals have only rarely been found. Siderite, in massive veins and in brown, prismatic microcrystals and subparallel aggregates, is associated with iron sulfides, sphalerite, franckeite and wurtzite. Siderite pseudomorphs after fluorapatite were reported by Gordon (1944).

Sigloite $FeAl_2(PO_4)_2(OH)_3\cdot 7H_2O$

Sigloite was described by Hurlbut and Honea (1962) as white or yellowish, opaque pseudomorphs after paravauxite, sometimes

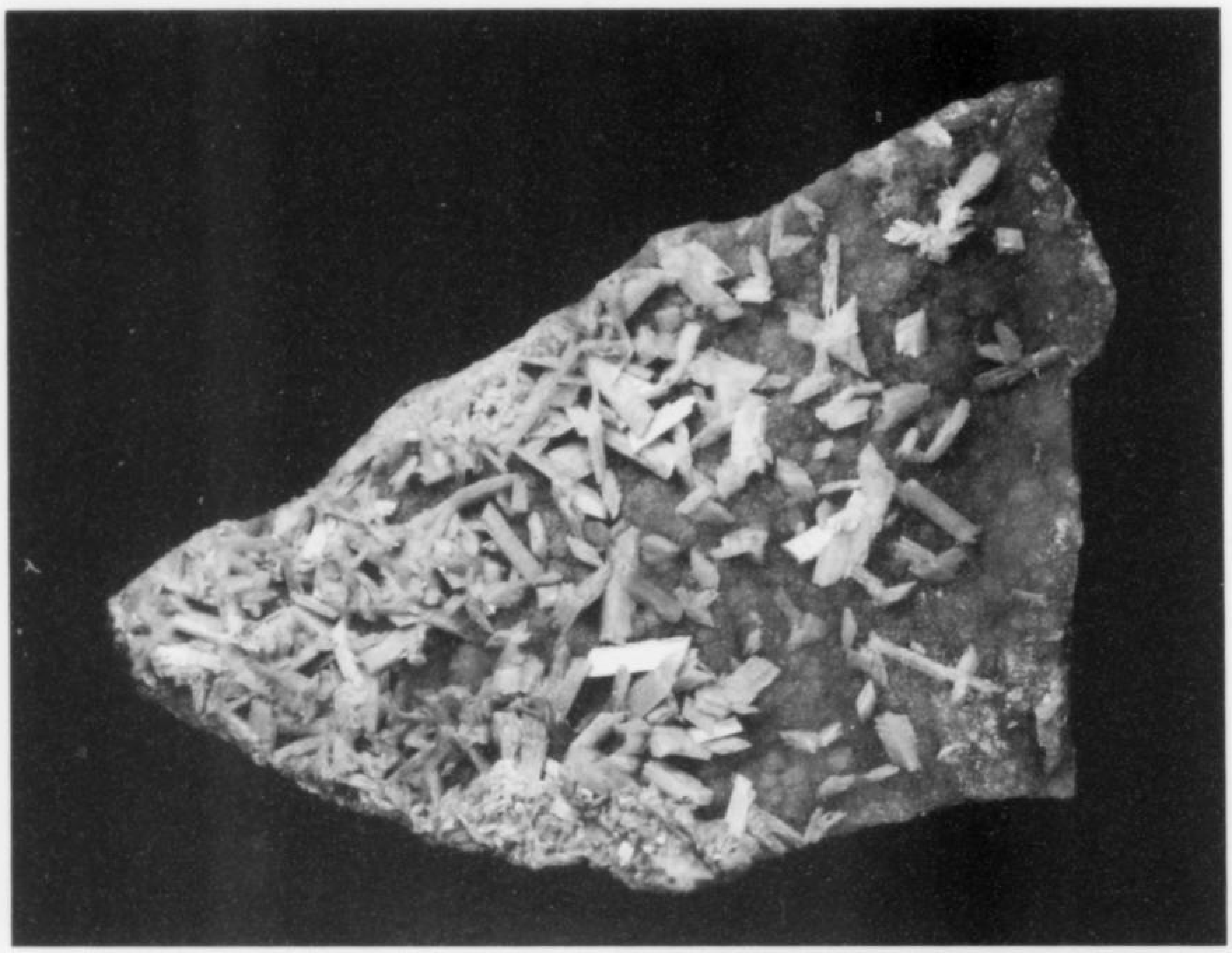


Figure 88. **Sigloite pseudomorphs after paravauxite crystals on matrix, 6 cm, from Llallagua. Hyrsl collection and photo.**

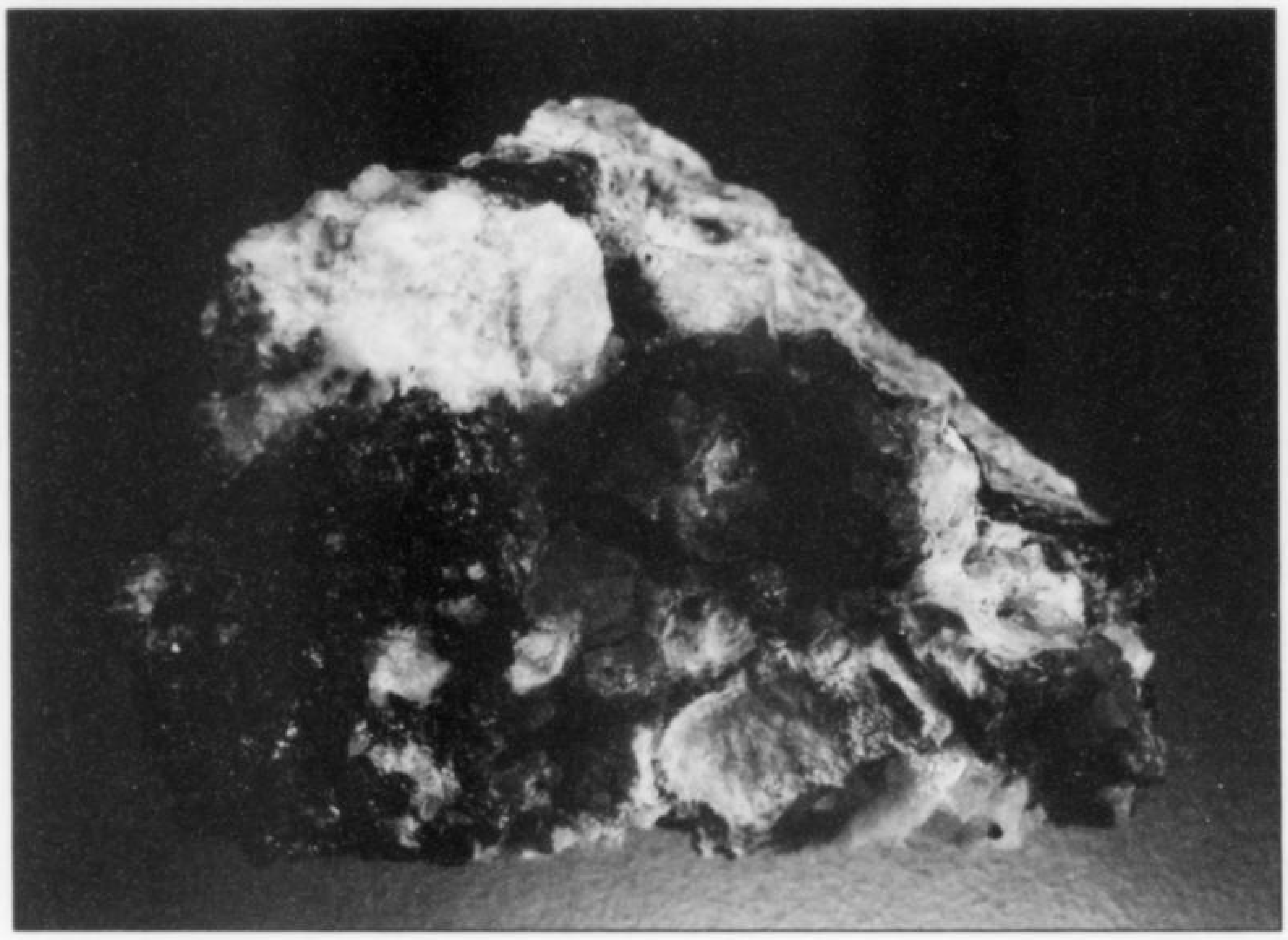


Figure 89. **Sphalerite colored red by realgar inclusions, 3.8 cm, from Llallagua. Hyrsl collection and photo.**

resting on orange childrenite. This is probably the same material that Bandy referred to as "hydrated paravauxite" (Bandy, 1944). Some so-called "sigloite" on the mineral market is actually misidentified childrenite. Crusts of pale brown sigloite crystals have been found quite commonly, but were often discarded in the past as merely "weathered paravauxite."

Silver Ag

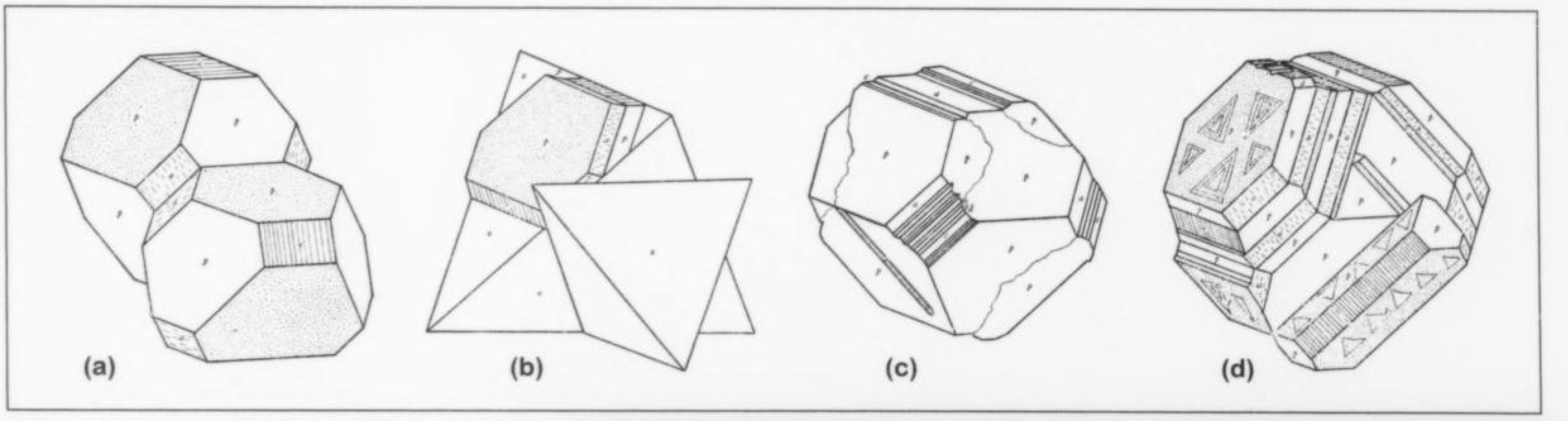
A specimen with native silver coating small tetrahedrite crystals is mentioned by Gordon (1944), but it is not certain whether it really came from Llallagua. It is feasible that the specimen could have come from one of the peripheral pyrargyrite-bearing galena veins.

Sphalerite ZnS

Sphalerite is common at Llallagua, in crystals to 1 cm, commonly wholly or partially replaced by younger stannite. Abundant small crystals of brown-black iron-rich sphalerite are occasionally found growing on the faces of larger pyrite crystals. Herzenberg (1933) described raspberry-red nodular to reniform masses of an arsenic-bearing sphalerite (0.64 weight % As) of colloidal origin, calling it *gumucionite* after Julio Gumucio, who was then chief mining engineer at Llallagua and is the only native-born Bolivian to have assembled an important mineral collection. (It was discredited as a mixture of sphalerite and realgar in 1970.) Pale pink to pale orange sphalerite masses of porcelaneous texture (looking not at all like sphalerite!) form part of the matrix in recently collected vivianite specimens.

Stannite Cu_2FeSnS_4

Stannite is much less common at Lllallagua than at Oruro, but its few surviving specimens are very probably the world's best for the



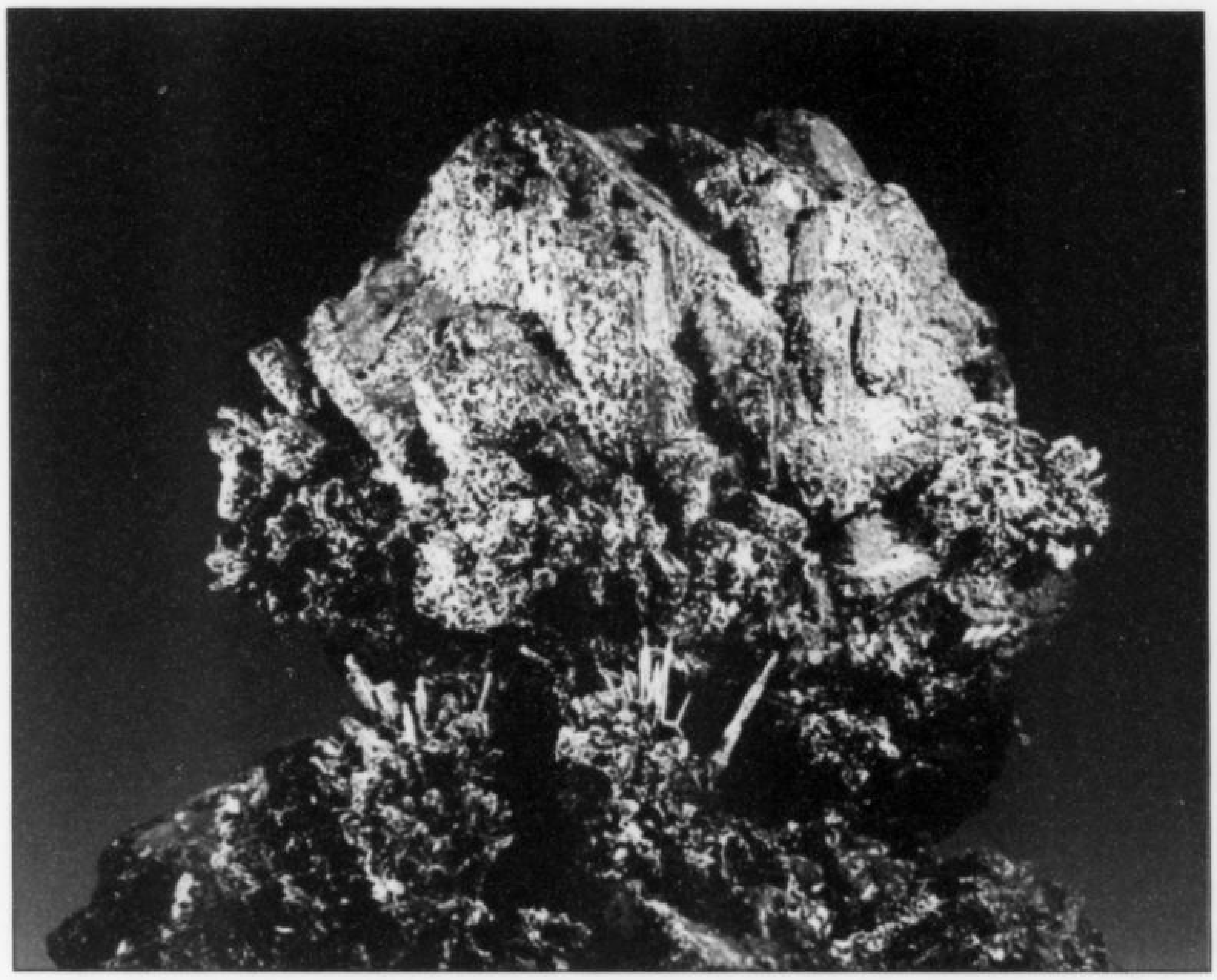


Figure 90. **Stannite from Llallagua; (a) contact twin on (111), (b) twinned crystal epitactic on sphalerite tetrahedron, (c) twin on (011), (c) polysynthetic twinning on (1110, and a contact twin on (011 at lower right. Crystal drawings by Gordon (1944).**

Figure 91. **Stannite crystal cluster, 8 cm, with needle-like crystals of free-growing cylindrite, from Llallagua. Natural History Museum of Los Angeles County collection; Anthony Kampf photo.**

species, even better than the new Chinese specimens from Yaogangxian. The best specimen is perhaps the one preserved at Harvard University, and an excellent specimen from Mark Bandy's collection is exhibited at the Natural History Museum of Los Angeles County. Sharp microcrystals of stannite can be found on some of the franckeite specimens collected in the 1990's.

Stannite at Llallagua is black to brownish steel-gray and usually massive. Crystals, when found, tend to be striated, with dull faces, and are sometimes twinned on (111) resulting in spinel-like twins and polysynthetic laminations. Less commonly, twinning on (011) results in triplets resembling simple cuboctahedra but with striated or sutured surfaces on {111}. A bluish to bronzy red or green tarnish is often present, and the association with sphalerite (which it resembles and sometimes replaces) can serve to distinguish it. Though stannite is tetragonal, the crystal forms {001}, {100}, {$1\bar{1}1$} and {111} commonly combine to simulate a cuboctahedron.

Stannite is most abundant in the southern third of the stock, especially in the upper portions of veins; the largest masses have been found in the Plata vein and its branches. Brilliant, well-developed crystals were found near the junction of the main Plata vein and Branch A, about 15 meters above Level 160. A large apatite-lined vug on Level 295 yielded abundant stannite crystals as well as sphalerite and prismatic cassiterite. Lustrous, well-formed crystals have also been found along the Bismarck vein, above Level 411, and stannite was locally abundant in the San José/San Fermin and Victoria veins as well. Franckeite and cylindrite are almost invariably associated with some stannite (Bandy, 1944).

Bandy (1944) reported that the prominent Bolivian mine owner and mineral collector Hans Block (a close associate of Frederick Ahlfeld) had in his collection exceptionally large crystals of stannite, to over 4 cm long and 2.5 cm in diameter, from the Salvadora vein, Level 1260. They were associated with equally large crystals of sphalerite, franckeite and rods of cylindrite.

Stibnite Sb_2S_3

Some gray acicular crystals are thought to be stibnite, though it is impossible to definitely identify by sight (Bandy, 1944). Gordon (1944) described masses of stibnite with orange-yellow stibiconite. It was abundant in the Angela mine, 7 km north of the intrusive stock (Bandy, 1944).

Sulfur S

Sulfur is found as minute yellow crystals, usually with bismuthinite or marcasite. According to Bandy (1944), some of this sulfur may be of primary origin, though Gordon (1944) believed it to be an alteration product of bismuthinite. Gordon (1944) depicts a sulfur crystal, rich in complex faces, found on marcasite on Level 446 of the San Pedro vein.

Teallite $PbSnS_2$

Teallite has been reported from Llallagua by Petrov *et al.* (2001), on the basis of information on specimen labels. However, the authors believe that the specimens in question are probably

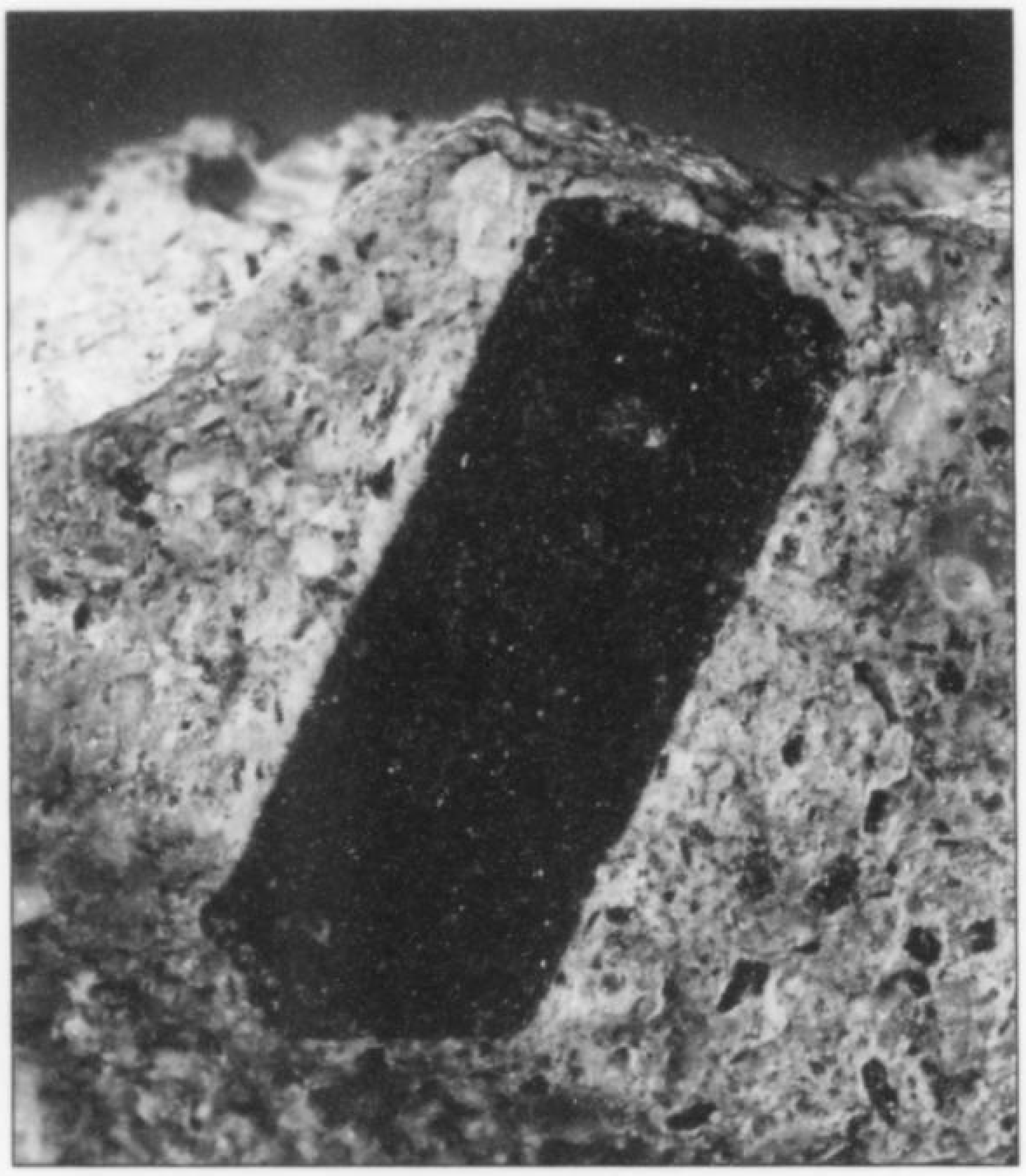


Figure 92. **Black tourmaline pseudomorph after feldspar, 2.5 cm, from Llallagua. Hyrsl collection and photo.**

mislabeled as to locality, and confirmation of the source is lacking. Therefore the occurrence at Llallagua must be considered doubtful.

Tenorite CuO

Gordon (1944) found black massive tenorite with chalcanthite in the Rosas vein.

Tetrahedrite Cu_3SbS_3

Small, black, tetrahedral crystals of tetrahedrite, usually twinned, occur with stannite and sphalerite at Llallagua.

Tetradymite Bi_2Te_2S

Tetradymite was described by Turneaure (1935) as inclusions in bismuthinite from the Contacto vein, Level 446.

Thorite $ThSiO_4$

Frondel (1958) reported thorite from hydrothermal sulfide veins in Llallagua, but this needs confirmation.

Tourmaline Group

A black mineral of the tourmaline group is one of the most common Llallagua species, because sericitization of feldspars was followed by tourmalinization, and practically all of the original feldspar in the porphyry was replaced by fine-grained tourmaline. Bandy (1944) reported tourmaline constituting up to 90% of black "breccia dikes" in the stock. Tourmaline also formed in the metamorphosed sediments around the stock. This process made the Llallagua intrusion one of the world's largest accumulations of tourmaline, although most of it occurs as felty or fibrous microcrystal masses and none of it is in the form of collector-quality crystals. Pseudomorph collectors may find the tourmaline pseudomorphs after Carlsbad twins up to 8 cm to be beautiful, and these can still be found on dumps and on the top of Cerro Salvadora. Micromounters will find acicular crystals, in several colors ranging from colorless to pale blue, pale green, greenish yellow and pale brown to brownish gray, in vugs in the altered volcanic stock, sometimes impaling spheres of younger phosphates.

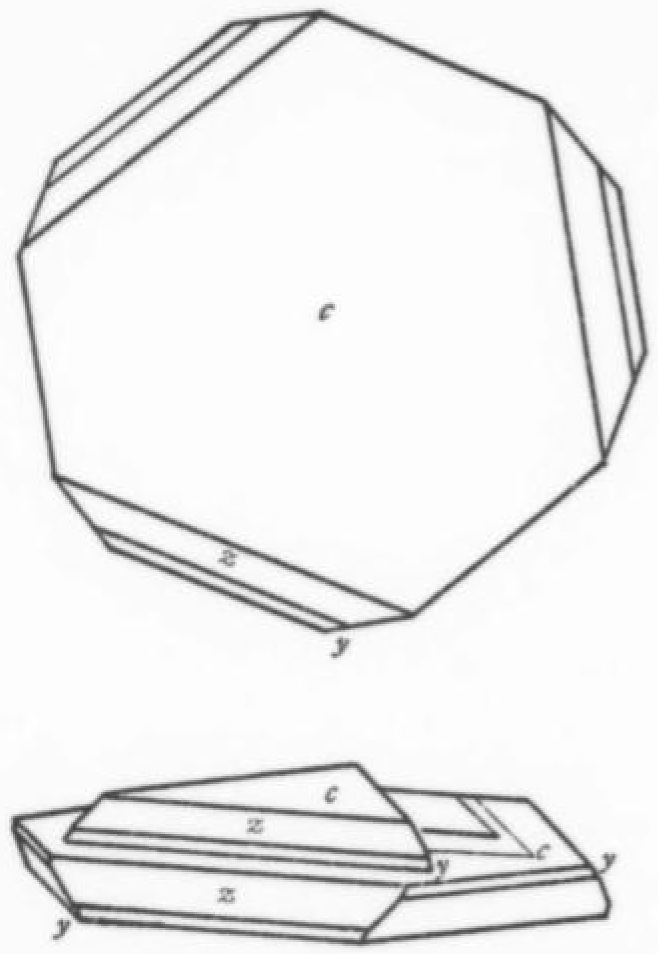


Figure 93. **Troilite from Llallagua; crystal drawings by Gordon (1944).**

Troilite FeS

Troilite, usually thought of as a meteoritic mineral, was identified by Gordon (1944) at Llallagua as extremely small crystals to 0.25 mm in tiny vugs in porphyry adjoining the San José vein. The sharp, tabular, rhombohedral crystals are yellow with a brilliant metallic luster.

Tungstite $WO_3{\cdot}H_2O$

Massive yellow tungstite (?) was found with wolframite in the oxidation part of the Blanca vein (Bandy, 1944).

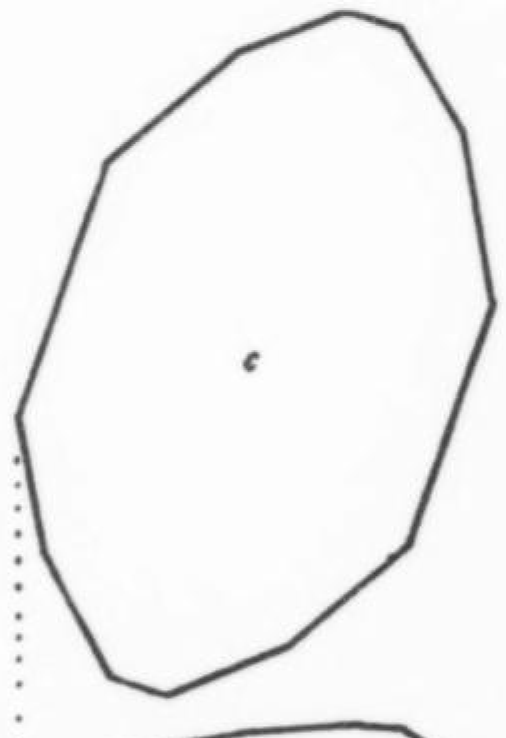


Figure 94. **Variscite from Llallagua; crystal drawings by Gordon (1944).**

Variscite $AlPO_4{\cdot}2H_2O$

Gordon (1944) depicts colorless tabular variscite crystals with large *c*-faces {001} bounded by the prism faces {010}, {100} and {120}, bevelled by small {111} faces. Normally, variscite at

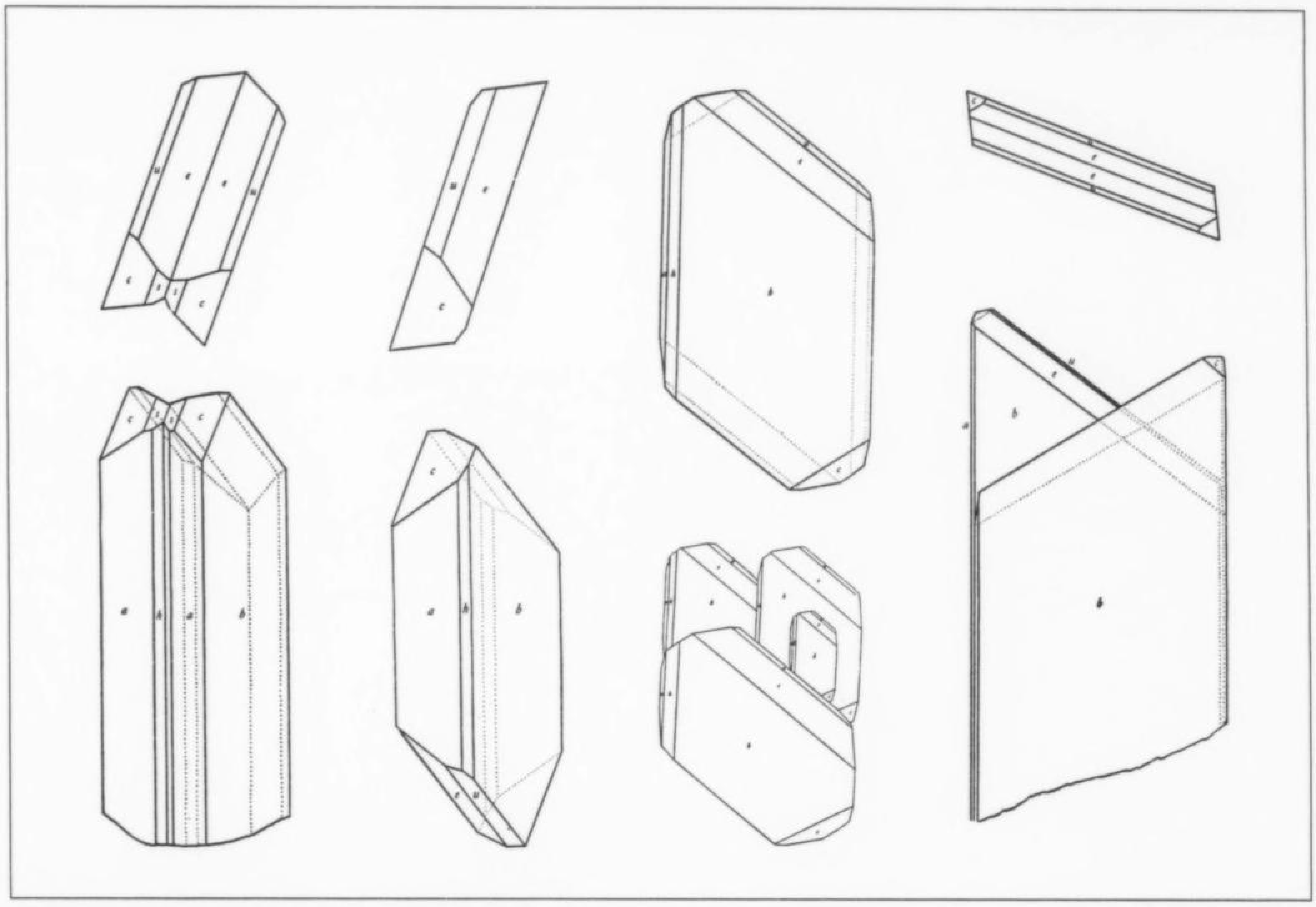


Figure 95. **Vauxite (twinned, untwinned and parallel growth) from Llallagua; crystal drawings by Gordon (1944).**

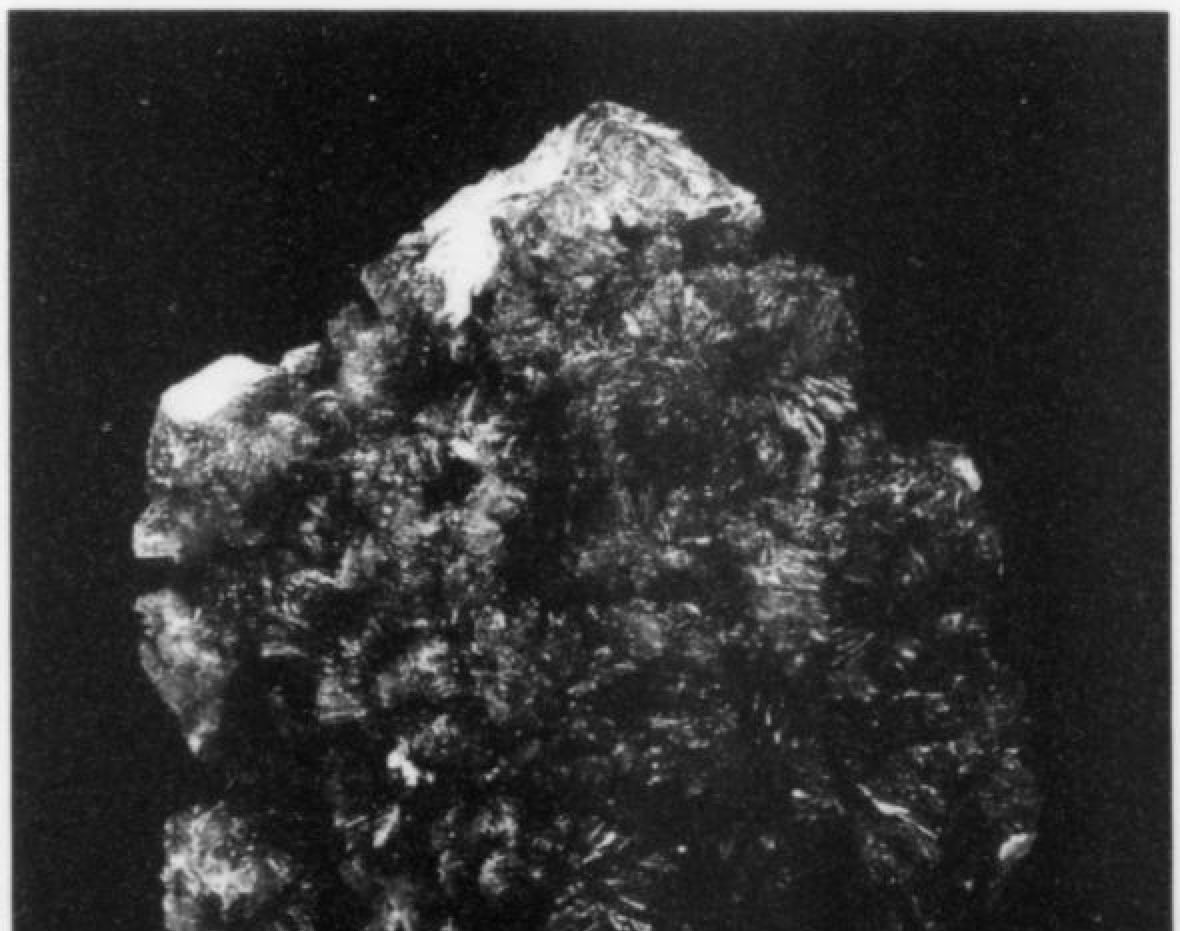


Figure 96. **Vauxite crystal crust, 3.6 cm, from Llallagua. Jeff Scovil photo; Dave Bunk specimen.**

Llallagua forms green-blue to blue and bluish white, smooth spherules with radial internal structure and waxy or glassy surface luster. Specimens showing variscite spherules perched on acicular tourmaline needles, and on quartz crystals in vugs left by the dissolution of orthoclase crystals in the porphyry, are still found commonly on the dumps. Pale blue waxy spherules of variscite on native bismuth were found underground in the early 1990's.

Vauxite $FeAl_2(PO_4)_2(OH)_2 \cdot 6H_2O$

Vauxite was described for the first time by Gordon (1923). Sky-blue to Venetian-blue crusts of tiny, vitreous, transparent, tabular vauxite crystals were found in almost all of the veins when Gordon visited Llallagua in the 1920's and again by Bandy in the 1940's. According to Bandy (1944) it generally occurs in sediments and in the stock near the contact with sediments. In the early 1940's the finest specimens were found lining open fissures on the footwall and hanging wall of the San José vein above Level 446. In one particularly large fissure in the footwall fine crystals in spherical aggregates were found perched on quartz, wavellite, marcasite and other minerals, associated with minor paravauxite. Small amounts were also found along the Contacto vein up to 400 meters from the stock. Fine specimens of vauxite on paravauxite were collected from a branch of the Serrano vein just east of the San José vein, above Level 446. However, on a branch of the San José vein on Level 446 Bandy (1944) found the reverse: metavauxite on vauxite. Fine specimens have also been recovered from the Bismarck vein. Vauxite has been seen on all levels below Level 383, and one fine specimen was collected higher up on Level 205.

Drusy vauxite commonly formed on mammillary allophane, which crumbles to powder upon dehydration, leaving a thin crust of pure vauxite with rounded impressions on the back. Radial aggregates forming nodules to 1 cm across were found in the early 1940's in the San José/San Fermin vein, on wavellite crusts covering quartz crystals (Gordon, 1944). It is also found on wavellite crusts covering porphyry breccia fragments in fault zones, and as thin but solid crusts covering paravauxite crystals. It

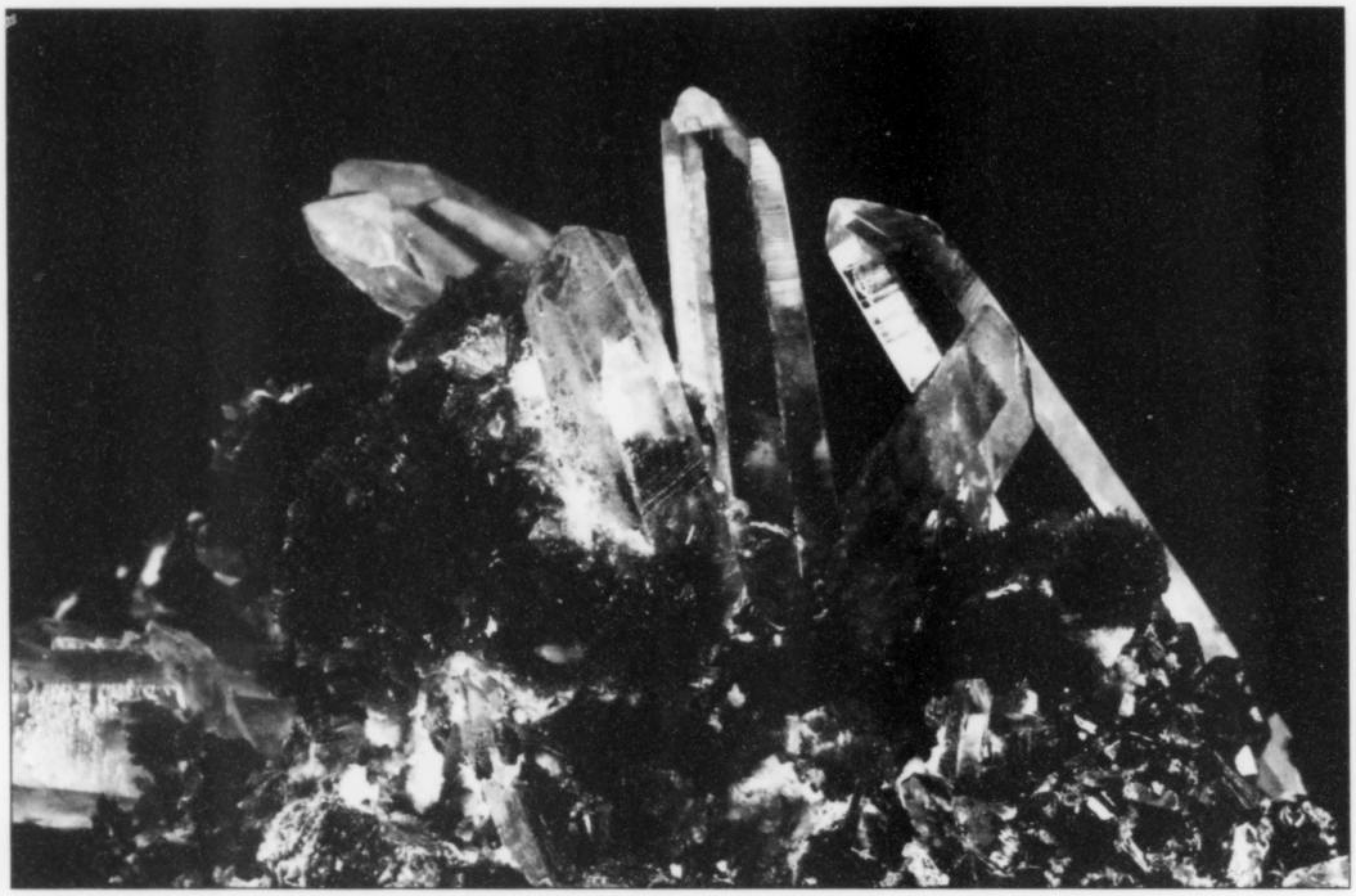


Figure 97. **Vauxite with quartz crystals to 1.9 cm and cassiterite, from Llallagua. Jeff Scovil photo; private collection.**

Figure 98. **Vauxite crystal crust, 7.4 cm, from Llallagua. William Larson collection; Wimon Manorotkul photo.**

has also been found rarely on cassiterite crystals in vuggy tin ore. The triclinic crystals are tabular on (010), and some are also twinned on (010).

Although Turneaure (1935) regarded the "vauxites" to be of supergene origin, Bandy (1944) considered them to be hypogene, with vauxite as the youngest mineral to form in the sequence wavellite→metavauxite→paravauxite→vauxite.

Very nice blue druses of vauxite were found again in the summer of 2001, accompanied by pearly white allophane and pink crandallite. Spheres of vauxite microcrystals are much rarer, but are sporadically found on quartz and cassiterite. Very beautiful greenish blue to bright blue spheres with diameters to about 3 cm were found in 2003. Surprisingly, yellowish brown to greenish brown crystals from this new find were shown by X-ray diffraction to be vauxite as well; apparently a very minor amount of oxidation is enough to change the color from blue to green-brown.

Vivianite $Fe(PO_4)_2 \cdot 2H_2O$

Before the famous discoveries of vivianite crystals at Morococala and Huanuni in the 1980's and 1990's, Llallagua was the source of the world's best vivianite specimens. Some of the biggest doubly terminated crystals were found in clay and reached 2 × 2 × 7 cm. Gordon (1944) reported extraordinarily perfect and beautiful, transparent, bottle-green crystals to 10 cm from the San José/San Firmin vein. In general the vivianite occurs on a matrix of botryoidal goethite derived from the alteration of pyrite and marcasite. The crystals are prismatic in habit, with a tendency toward parallel growth.

Surprisingly nice specimens were found in 2000; they show transparent, triangular tabular crystals up to 13 cm across, in many cases arranged in parallel rows like saw teeth, associated with childrenite, cronstedtite, pyrrhotite, franckeite and pink massive sphalerite.

Wavellite $Al_3(PO_4)_2(OH,F)_3 \cdot 5H_2O$

Wavellite is one of the most abundant Llallagua minerals, occurring usually as white or pale yellow coatings, crusts and radial aggregates on quartz and cassiterite druses. Llallagua wavellite

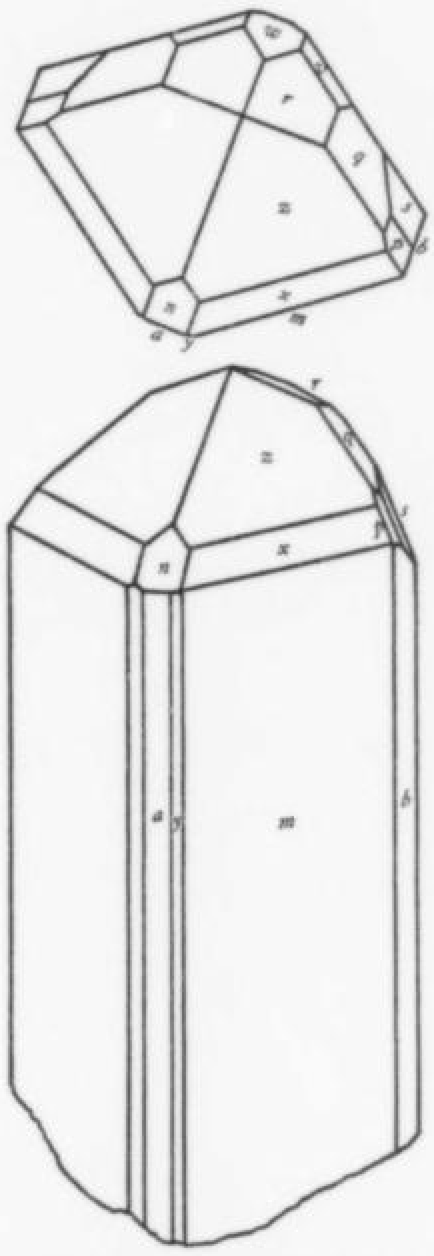


Figure 99. **Vivianite from Llallagua; crystal drawings by Gordon (1944).**

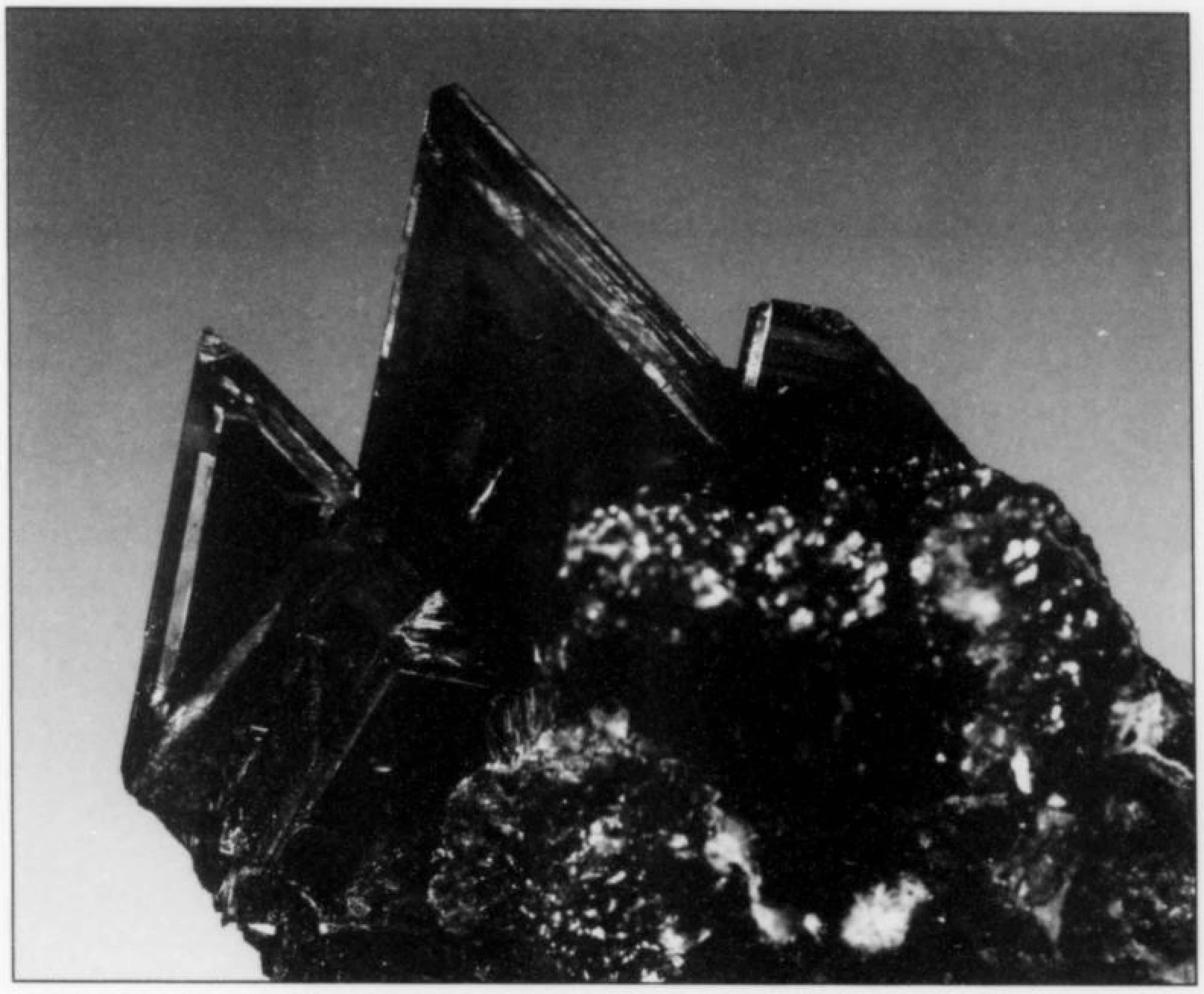


Figure 101. **Vivianite crystals in parallel growth, 2.5 cm, from Llallagua. Hyrsl collection and photo.**

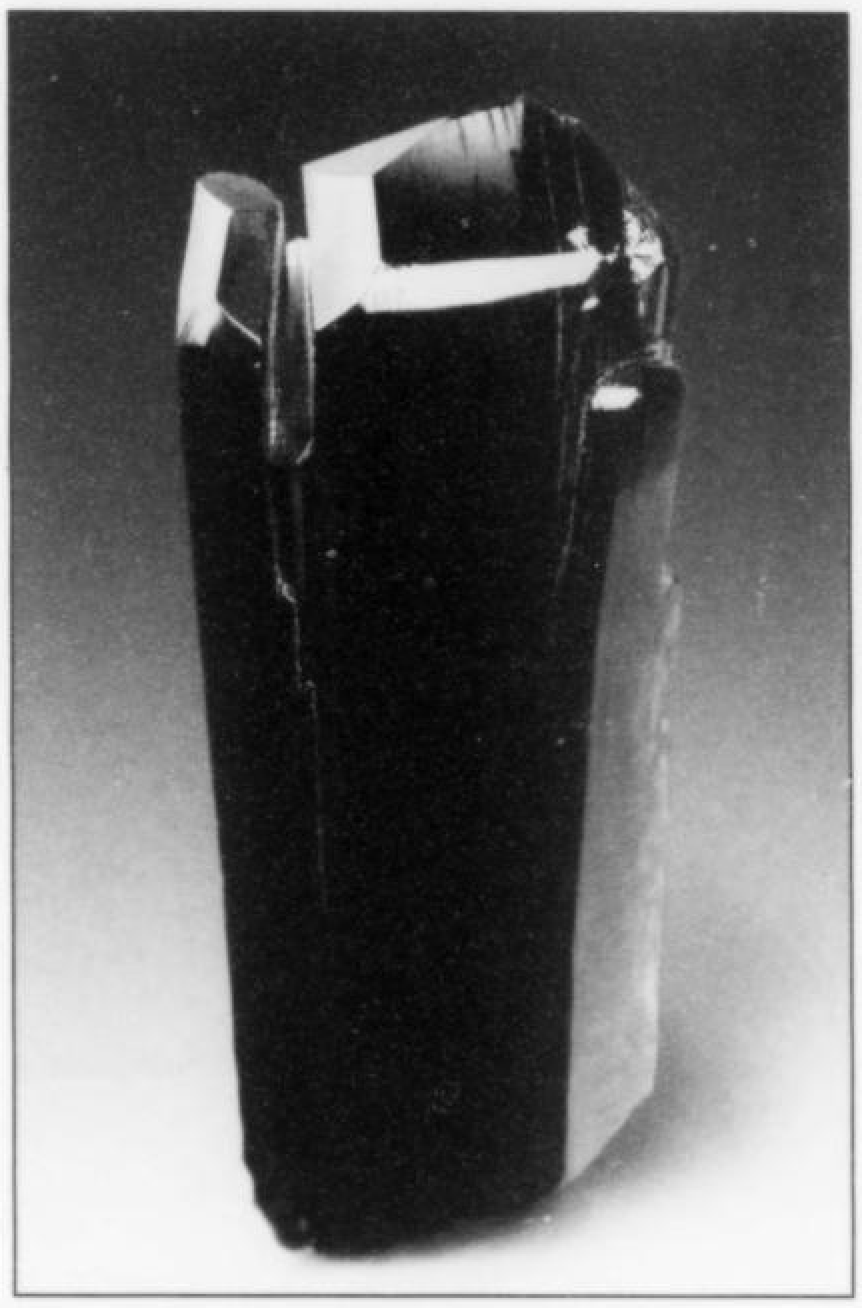


Figure 100. **Vivianite crystal, 7 cm, from Llallagua. Fred Kennedy collection; Wendell Wilson photo.**

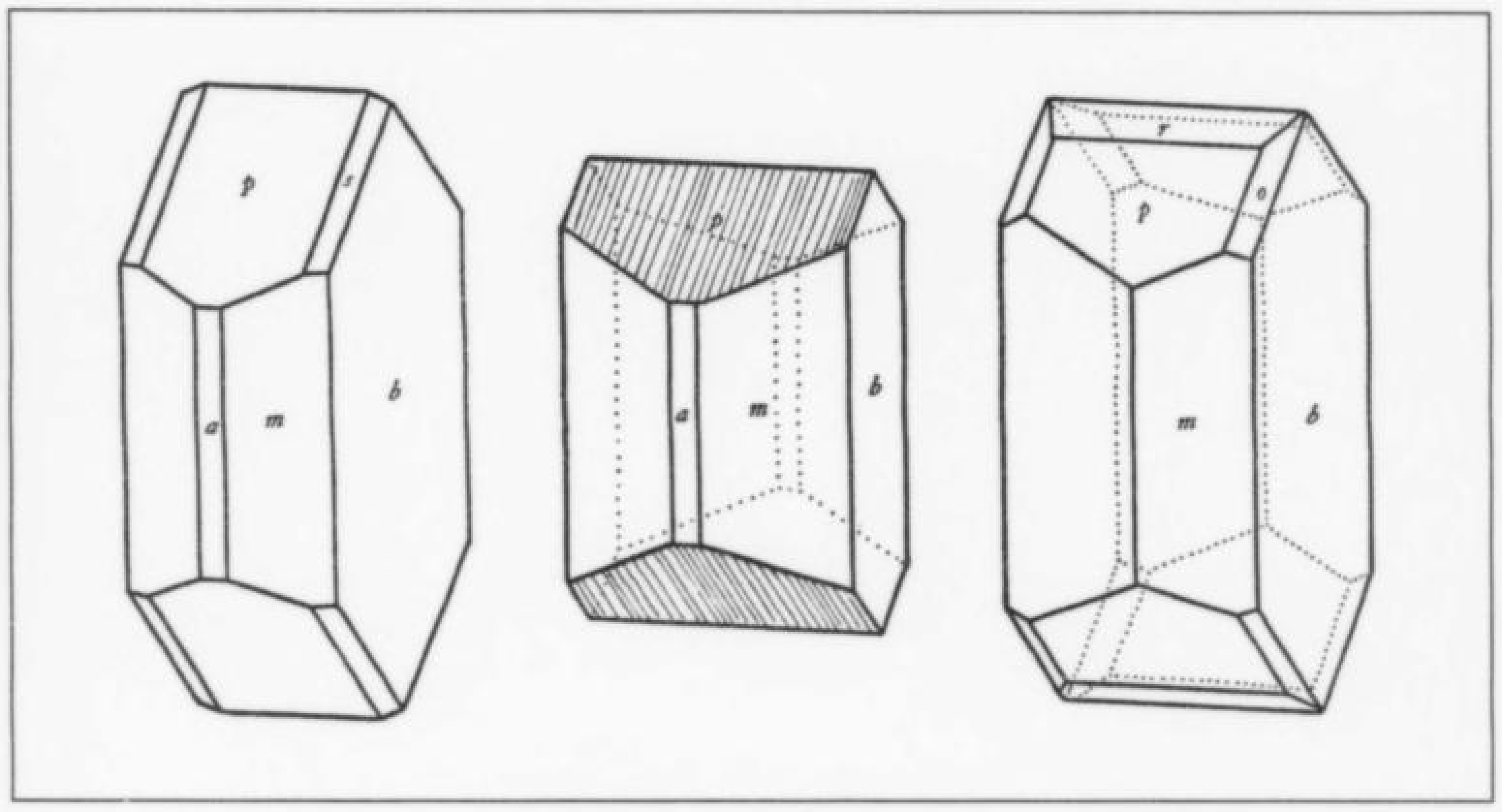


Figure 102. **Wavellite from Llallagua; crystal drawings by Gordon (1944).**

can be colorless, white or pale yellow, and rarely orange or pale grayish green, but is never bright green like the Arkansas specimens. Colorless single crystals up to 5 mm have been commonly found in the deeper parts of the mine, below Level 383. Bandy (1944) observed a rough correllation between crystal size and depth. Quartz is sometimes covered by wavellite spheres with a radial structure, to 4 cm in diameter. Fine druses of wavellite invariably form the substrate for the growth of large crystals of vauxite, paravauxite, childrenite and large crystals of wavellite. Wavellite also forms pale orange epimorphs after large tabular fluorapatite crystals.

Wavellite crystals, at least the better-formed ones, are transparent to translucent and colorless to pale green or pale yellow, with a vitreous luster (sometimes pearly on the prism faces). Crystals are prismatic to tabular on (010), with a perfect cleavage parallel to (110).

The San José vein on and above Level 650 has produced the most good specimens, with crystals to 4 mm. A few doubly terminated crystals have been found in the Uno A vein on Level 481. Most of the good specimens of wavellite in spherical clusters (to 3 cm in diameter) have come from the lower levels of the San José vein; the surface of these spheres is composed of crystal terminations. The finest specimens have come from quartz-lined vugs lacking any other associated minerals. Attractive yellow spheres have been found in the San Miguel vein, Level 383, and the San José vein, Level 620. Wavellite coating quartz with a thin film of red greenockite and black sulfides came from the Reggis and Forastera veins below the sulfide horizon. The Contacto vein below the sulfide horizon also contains quartz crystal vugs thickly covered by drusy wavellite. Small pellets to 3 mm are found throughout the mine (Bandy, 1944).

Nice yellow wavellite spheres to 1 cm in diameter with fluorapatite crystals on quartz were found in 2002.

Wickmanite $MnSn(OH)_6$

Tiny yellow octahedral crystals of wickmanite were identified by Kampf (1982) as the host crystals for epitactic overgrowths of orange-brown jeanbandyite crystals.

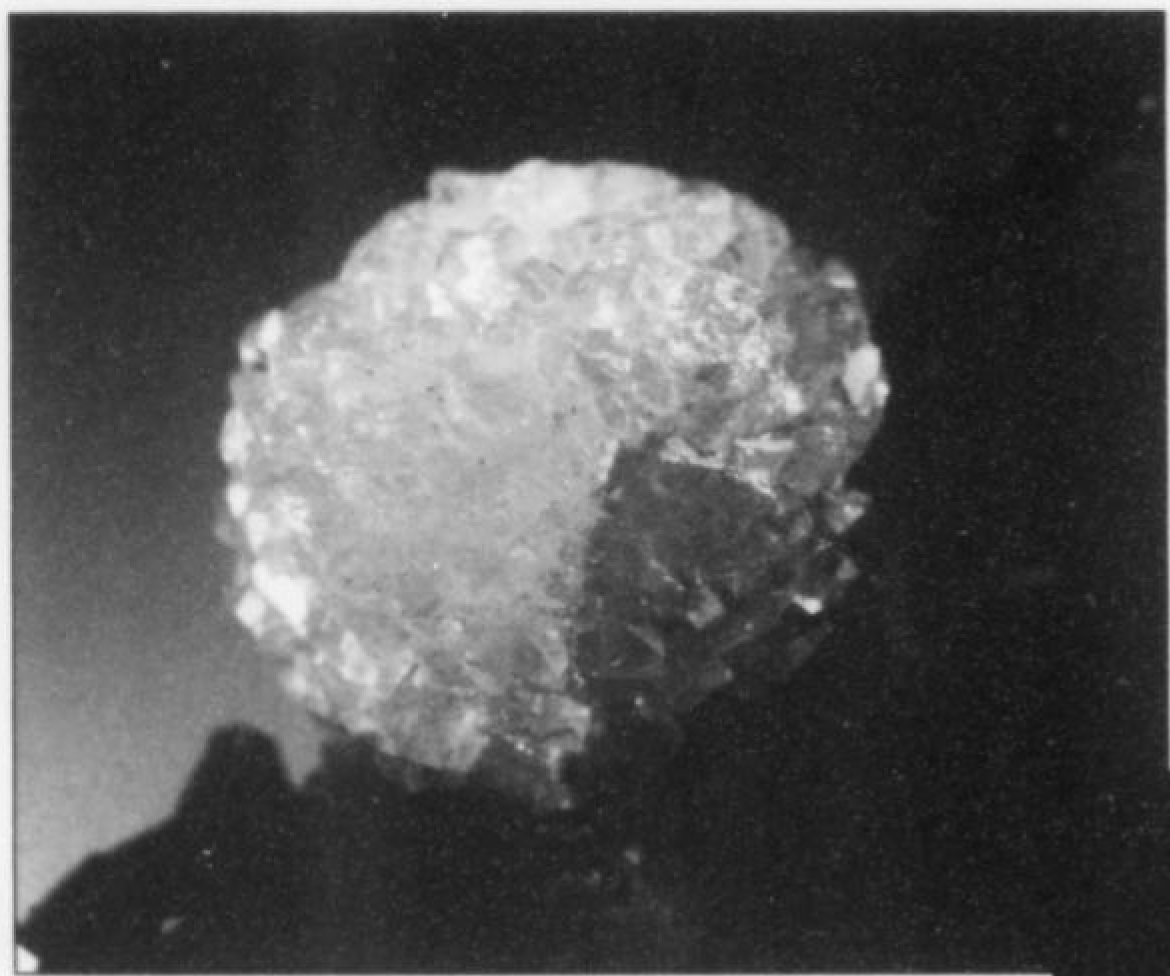


Figure 103. **Wavellite crystal spherule, 9 mm, from Llallagua. University of Arizona collection; Wendell Wilson photo.**

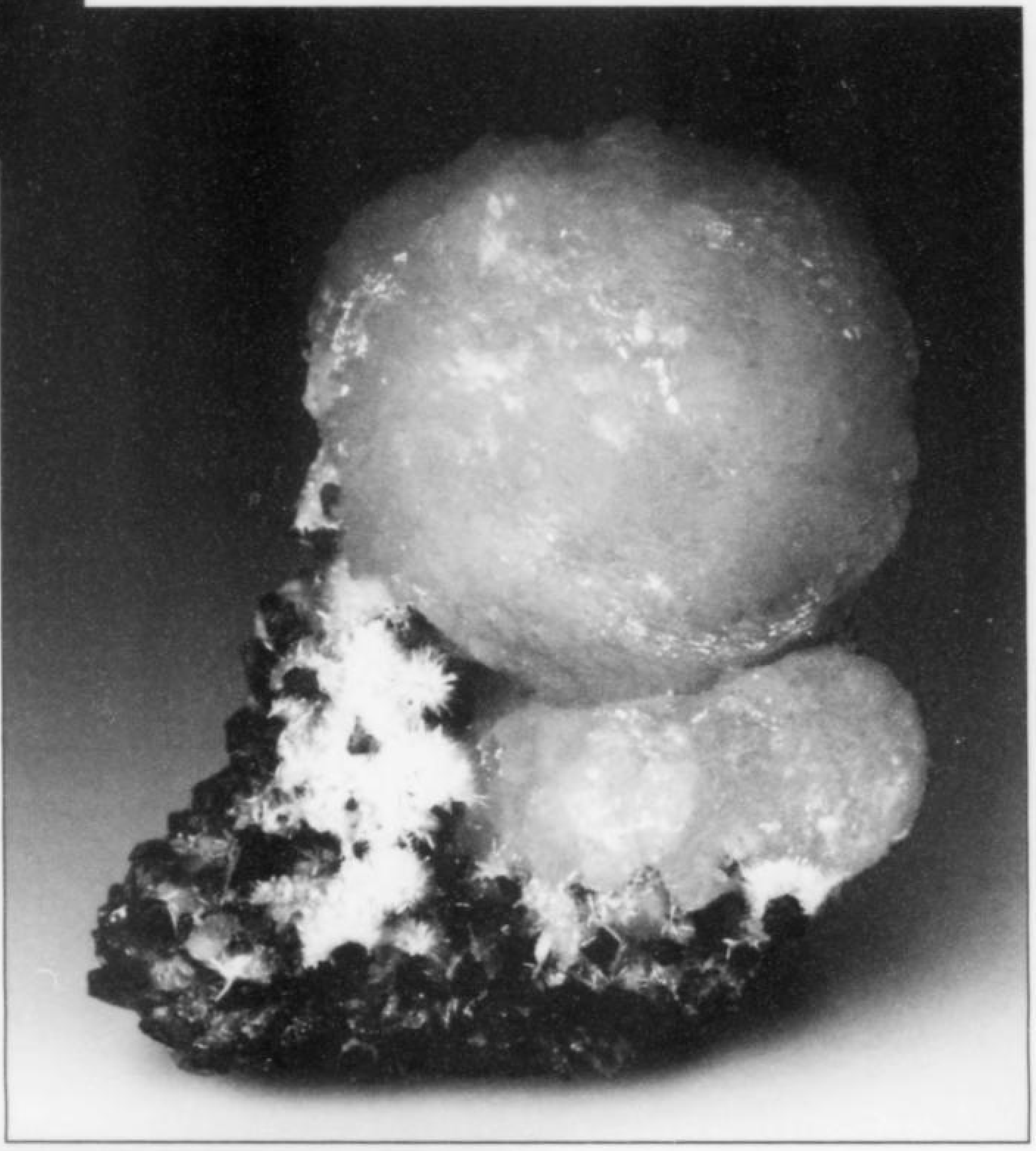


Figure 104. **Cream-colored wavellite spherule 3.5 cm, on matrix from Llallagua. Smithsonian Institution collection; Rock Currier photo.**

Figure 105. **Colorless wavellite specimen, 6 cm, from Llallagua. Seaman Mineral Museum collection, Michigan Technological University; John Jaszczak photo.**

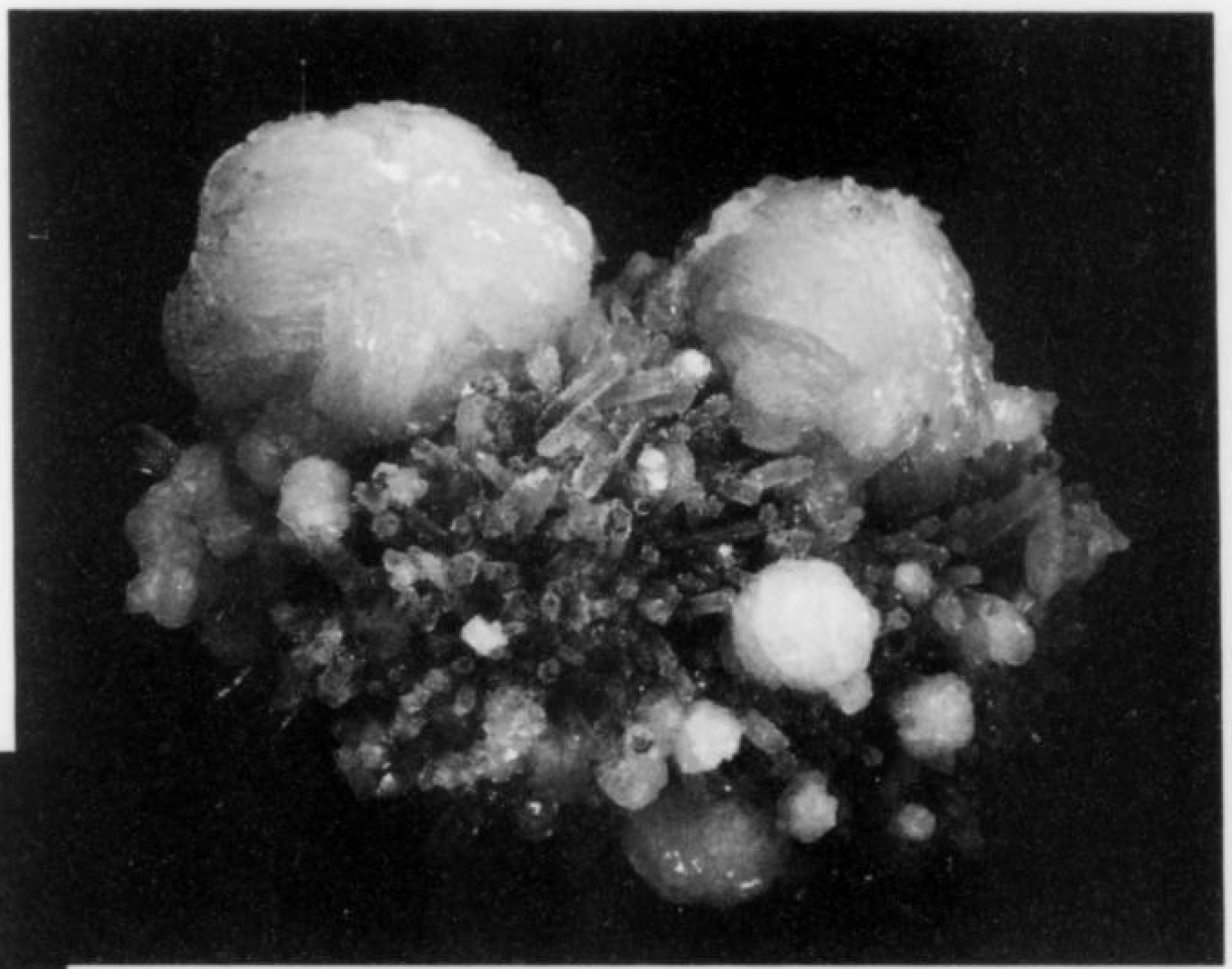


Figure 106. **Yellow wavellite spheres on quartz, 6.7 cm, from Llallagua. Les Wagner collection; Jeff Scovil photo.**

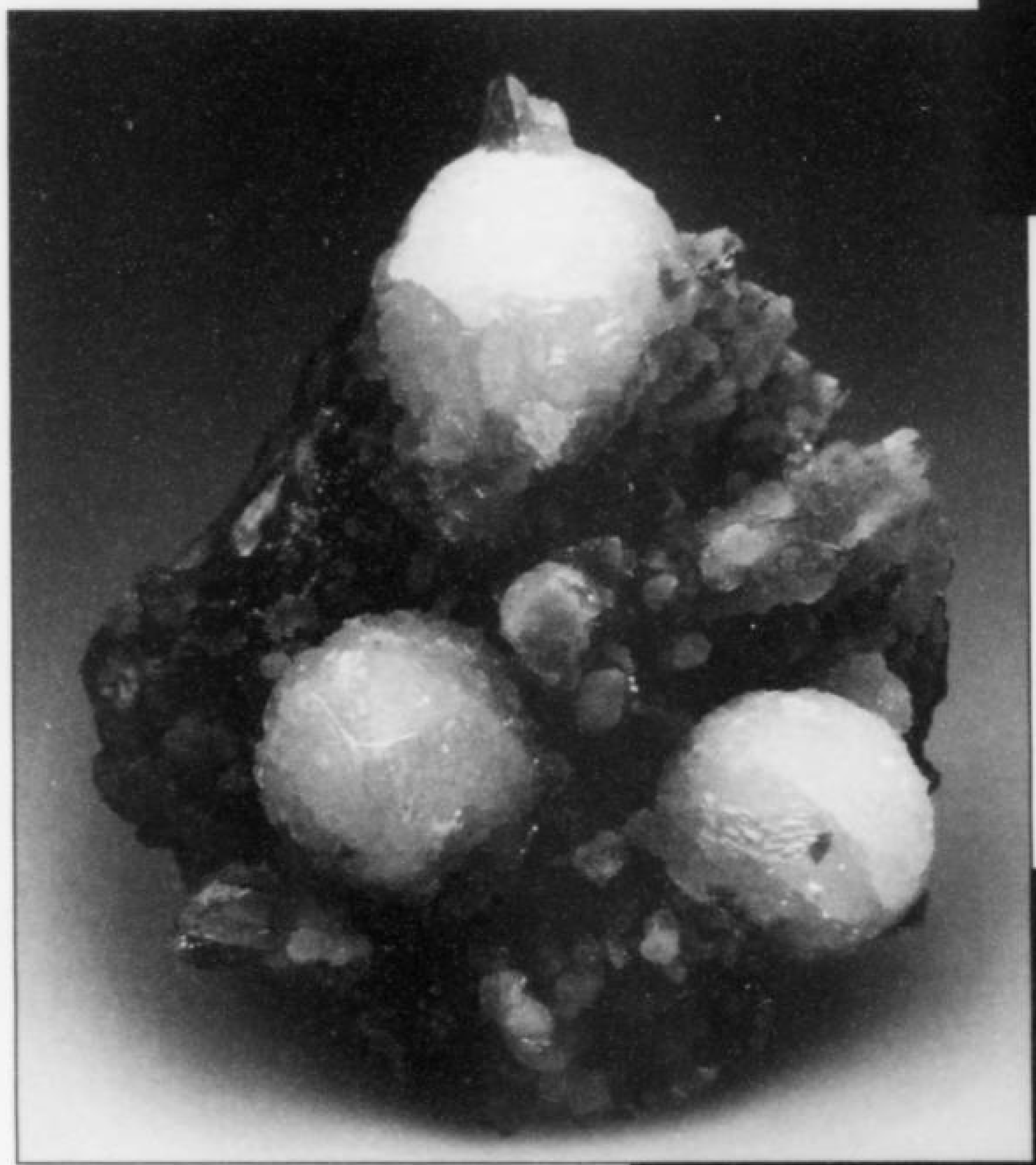


Figure 107. **White wavellite spheres on matrix, 5.2 cm, from Llallagua. Martin Zinn collection; Jeff Scovil photo.**

Wurtzite ZnS

Well-formed, tabular to blocky, brilliant brownish black wurtzite crystals are famous from several Bolivian deposits, and are not uncommon in the secondary veins at Llallagua. Crystals of wurtzite to several centimeters were said to have been found in the early days at Llallagua, but few were preserved. Wurtzite at Llallagua forms rosettes of tabular crystals, large and fine hemimorpic crystals, fibrous masses, and interlaminations in marcasite/pyrite replacements of pyrrhotite, associated with galena, franckeite and a carbonate (siderite or rhodochrosite). Wurtzite replacements of pyrrhotite developed along basal parting planes and so the resulting pseudomorphs tend to retain the original orientation. In vugs,

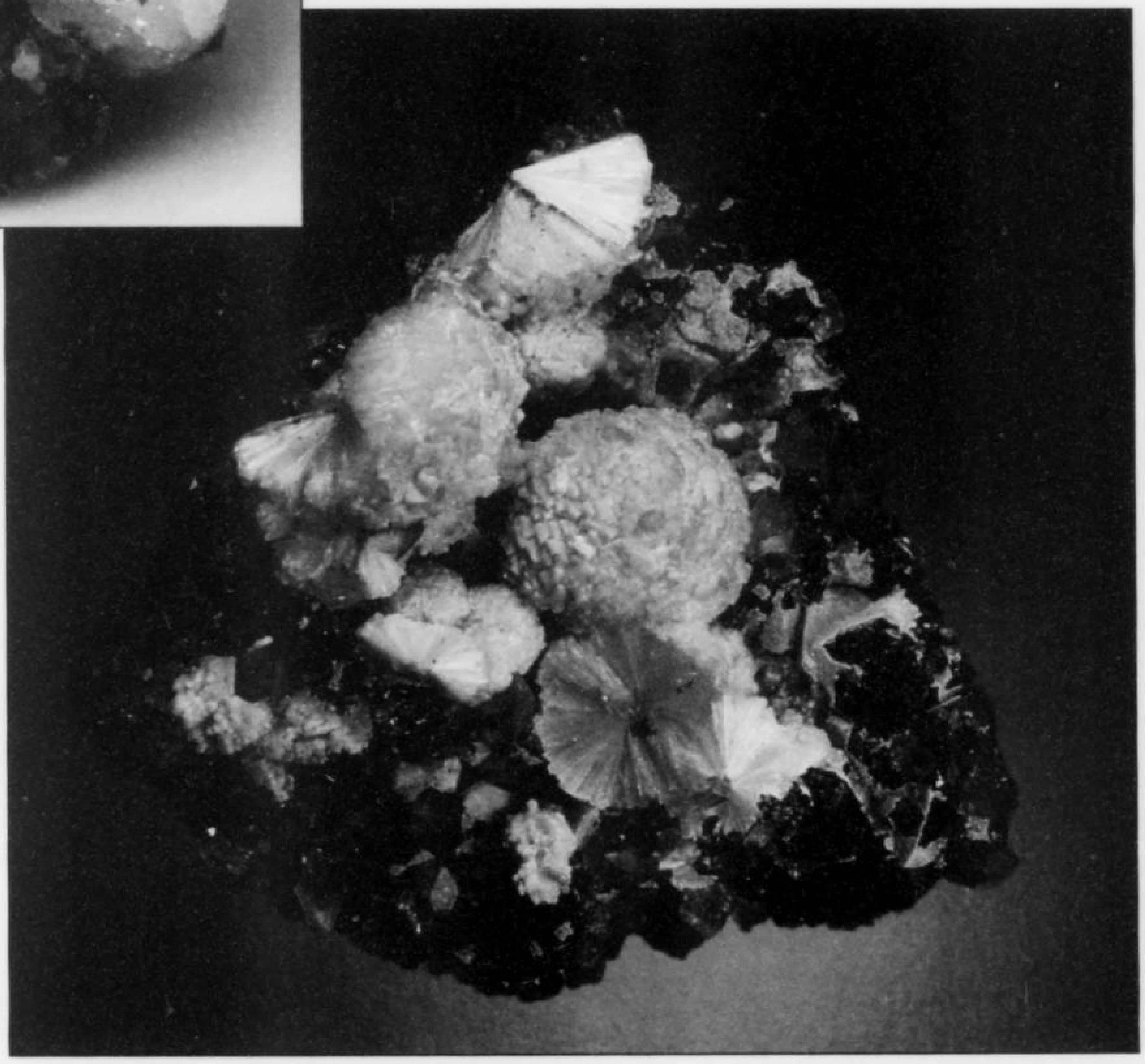


Figure 108. **Wavellite spherules on cassiterite, 6 cm, from Llallagua. Hyrsl collection and photo.**

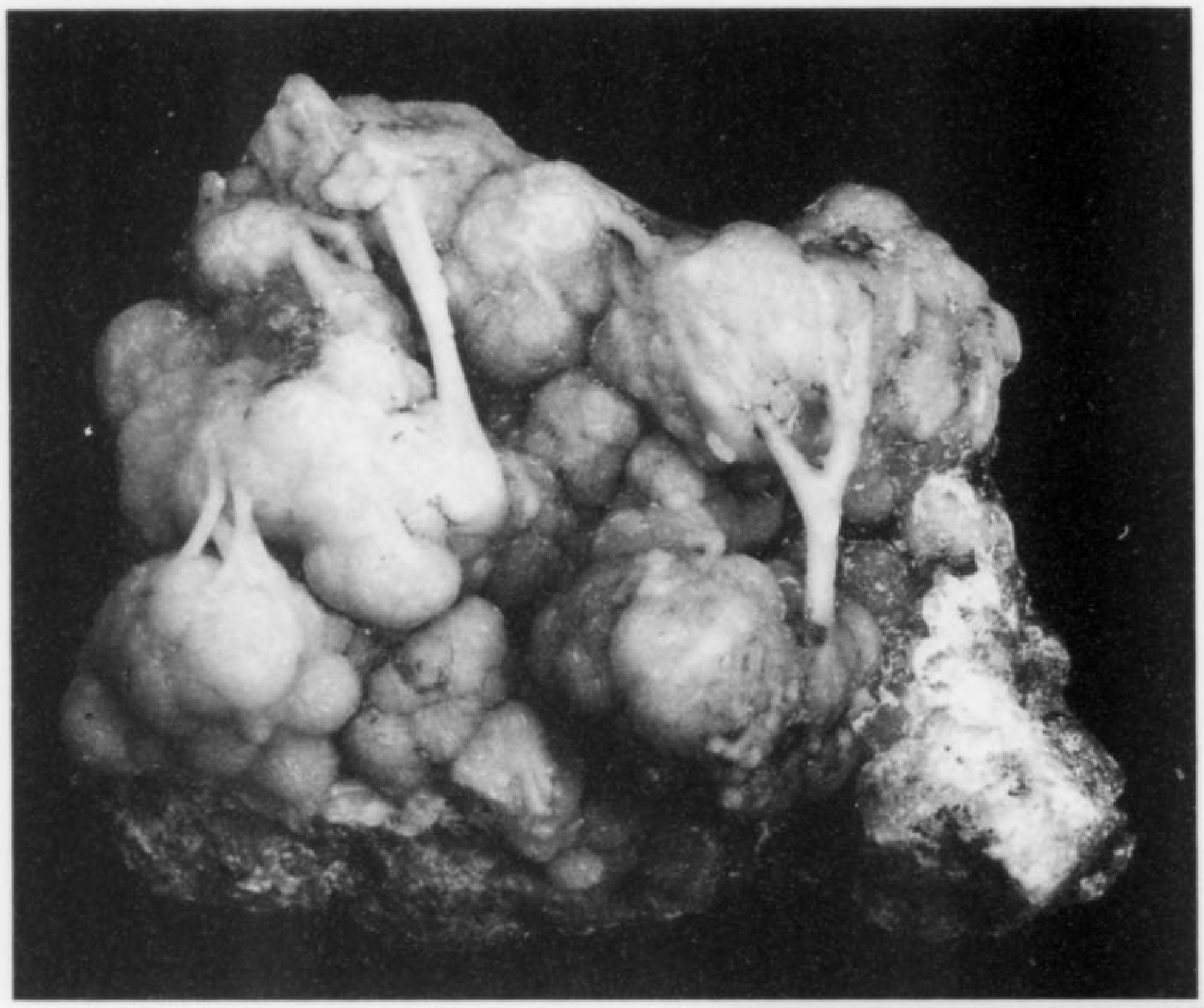


Figure 109. **Stalactitic wavellite, 7.5 cm, from Llallagua. Hyrsl collection and photo.**

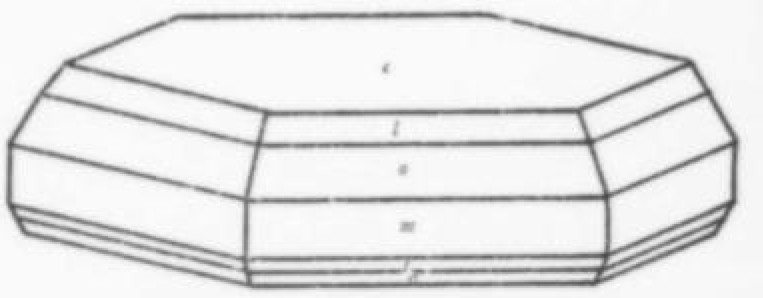


Figure 110. **Wurtzite from Llallagua; crystal drawings by Gordon (1944).**

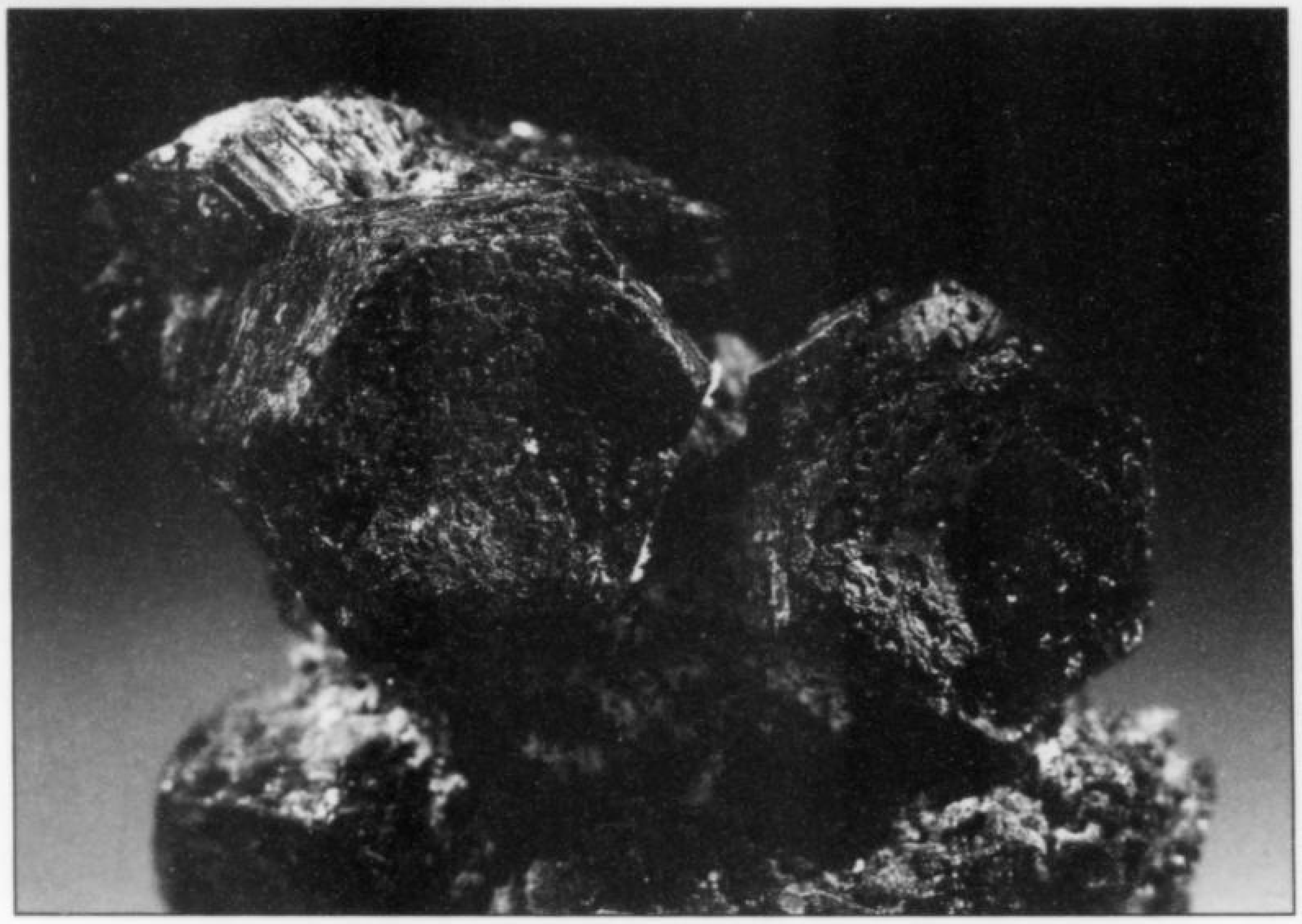


Figure 111. **Wurtzite crystal cluster, 1.2 cm, from Llallagua. Forrest and Barbara Cureton collection; Wendell Wilson photo.**

wurtzite forms subparallel to radial aggregates and individual crystals to 2 cm or more. Most wurtzite crystals have inverted to sphalerite (Gordon, 1944).

Fibrous wurtzite occurred in some of the north-central veins between Level 383 and Level 516, as coatings on sphalerite. Tabular crystals and rosettes were found in vugs in the upper levels of the Contacto vein, associated with sphalerite, wolframite and franckeite. Large hemimorphic crystals to 1 × 1 cm were found perched on a layer of franckeite on Level 190 south of the Plata vein. Good crystals to 3 mm on brilliant crystals of marcasite have been found on the San Pedro vein, above Level 446 (Bandy, 1944). Ahlfeld and Muños Reyes (1955) also described fine crystals from the Salvadora vein, associated with franckeite, wavellite and vauxite. A specimen composed entirely of black wurtzite crystals up to 1 cm and weighing 600 grams is in a private German collection. A few tapering, pagoda-like crystals to 2 cm were found in vugs in pyrite in the Dolores Section in the mid-1990's.

Xenotime-(Y) YPO_4

Dark yellow prismatic xenotime-(Y) crystals are much rarer at Llallagua than the associated monazite crystals. Rarely, both species form inclusions in quartz. Gordon (1944) cited crystals up to only 1 mm, and Ahlfeld and Muños Reyes (1951) described xenotime-(Y) crystals reaching only 2 mm, but at least one fantastic Llallagua specimen is exhibited in the Natural History Museum in London. It is a 4 × 7-cm matrix covered by yellow monazite crystals to about 9 mm, with smaller, pale green xenotime-(Y) crystals. Bandy (1944) reported good crystals from the Bismarck vein (between Levels 411 and 383), as well as several places on the Animas branch M vein (between Levels 305 and 215).

Zinkenite $Pb_9Sb_{22}S_{42}$

Zinkenite has been reported from Llallagua by Petrov *et al.* (2001), on the basis of information on specimen labels. However, the authors believe that the specimens in question are probably

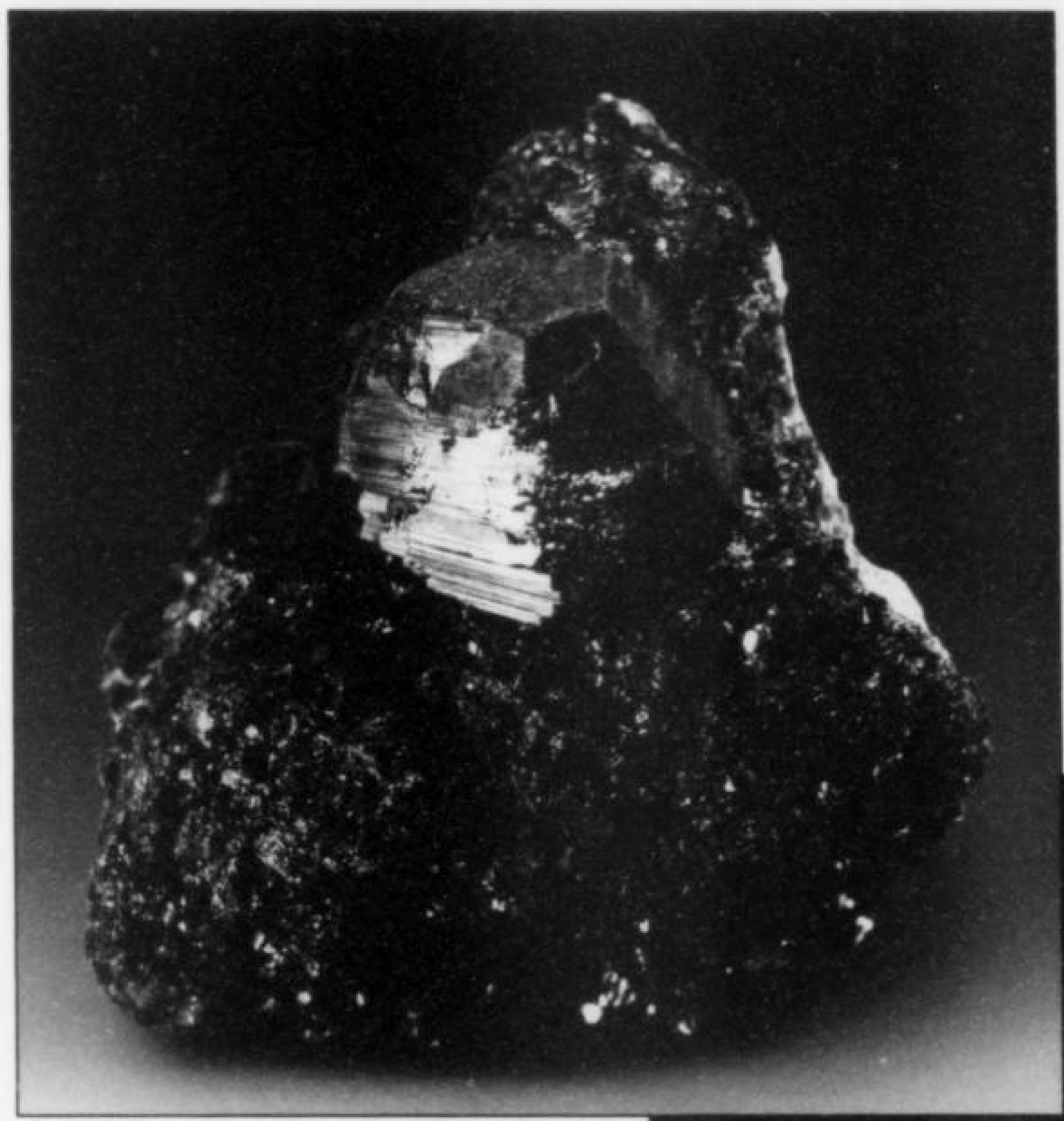


Figure 112. **Wurtzite crystal, 1.5 cm, from the Animas Section, Level 190, Llallagua. Bandy collection, Natural History Museum of Los Angeles County; Anthony Kampf photo.**

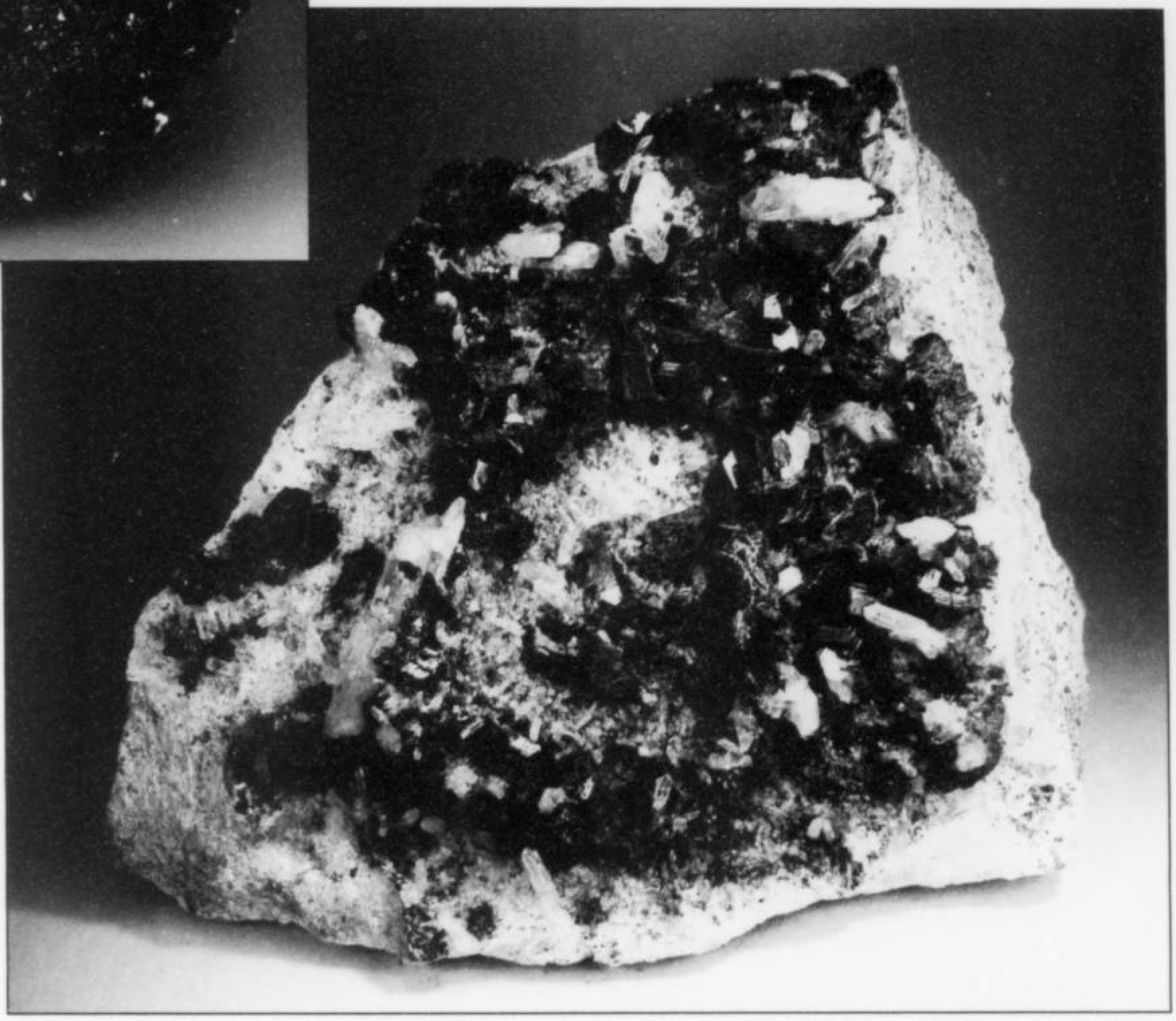


Figure 113. **Wurtzite with quartz on matrix, 16 cm, from the Inca vein, Level 383, Llallagua. Bandy collection, Natural History Museum of Los Angeles County; Anthony Kampf photo.**

mislabeled as to locality, and confirmation of the source is lacking. Therefore the occurrence at Llallagua must be considered doubtful.

CURRENT COLLECTING POSSIBILITIES

Llallagua is a *cooperativa* (meaning that it is jointly owned by the miners themselves) presently being worked by many thousands of very poor miners, who are laboring under very primitive conditions. They exploit the remains of tiny cassiterite veins underground, or rework old dumps. Only a few of them have any idea what a mineral specimen for a collection should look like; accordingly, some of the workers keep broken druses of quartz with cassiterite as decorations at home, but well preserved specimens are rare.

When the authors visited Llallagua for the first time together on a Saturday in 1993, we asked several miners for mineral specimens. The answer was always the same: "You are lucky, today is concentration day." We didn't understand until people brought us sacks full of powdered cassiterite, and whined "But why don't you want it? It's so pure!" We were not able to get even one specimen during this first visit. Since then, a few miners have learned about the specimen market, and small lots of crystallized specimens, mostly phosphates, occasionally appear at mineral shows.

The good news is that visitors can go field collecting on the enormous dumps. The authors have found nice pseudomorphs of tourmaline after feldspar and pyrite after feldspar. We have also found vugs with crystals of monazite, wavellite, florencite-(Ce), cassiterite, jeanbandyite and other species. Other interesting minerals are certainly still waiting to be found on the dumps, but these will delight mainly micromounters, as the chances of digging a nice cabinet specimen out of the dumps are close to zero.

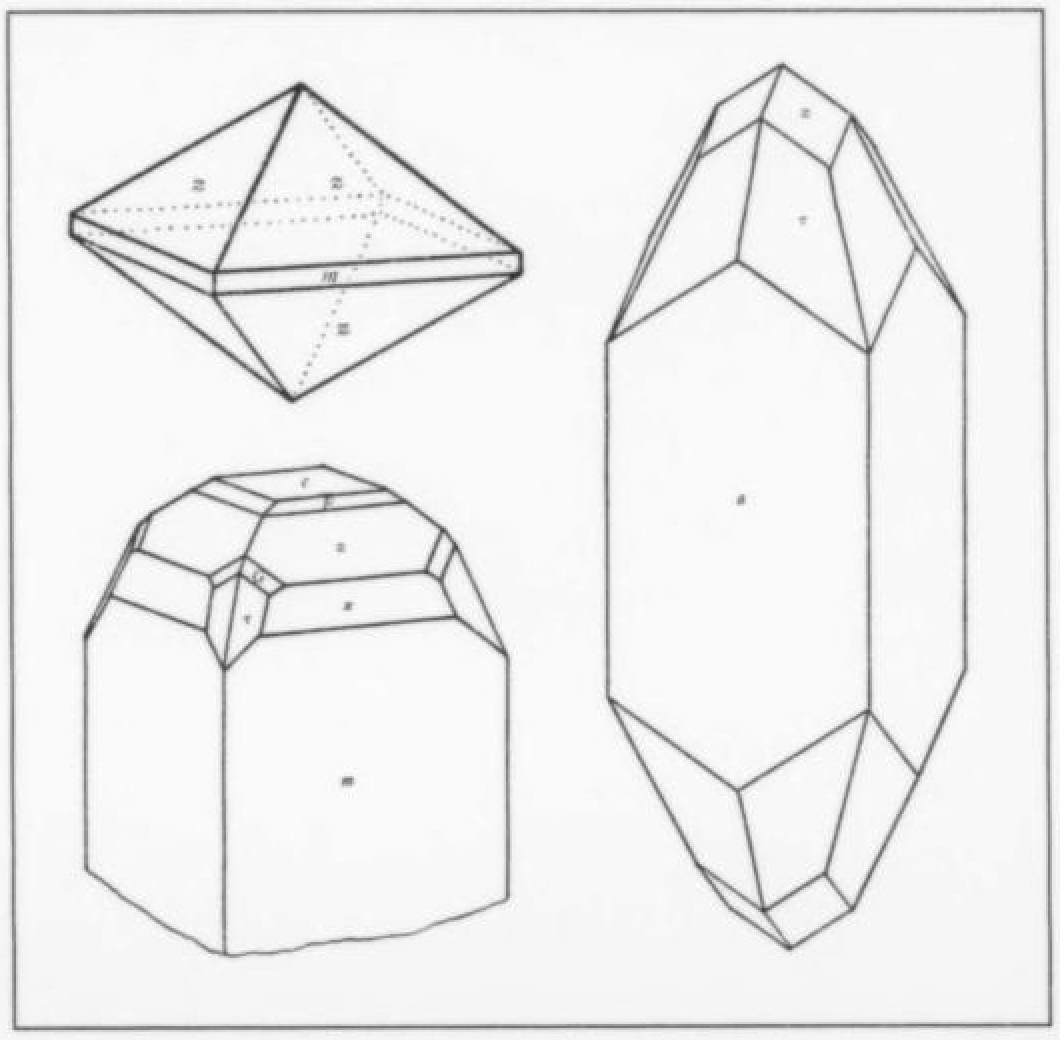


Figure 114. **Xenotime from Llallagua; crystal drawings by Gordon (1944).**

For a modest remuneration, and with permission from whichever cooperativa office is responsible for the Section one wishes to enter, Spanish speakers can arrange to accompany a miner underground to a working stope. Be forewarned that Siglo XX is dangerous underground. A friend of the authors died recently during a bumpy ride to the hospital after having broken multiple bones falling down a rotten ladder. You will get dirty and may encounter extreme temperatures, both hot and cold; safety rules will not be observed, you will not be able to sue anyone if you get injured, and you might have to stay underground for your miner's entire shift, as you might not be able to find your way back to the surface by yourself.

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BIBLIOGRAPHY

AHLFELD, F. (1929) Die Zinnerzgrube Uncía-Llallagua (Bolivia). *Metall und Erz*, **26** (14), 349–354.

AHLFELD, F. (1931) The tin ores of Uncía-Llallagua. *Economic Geology*, **26**, 241–257.

AHLFELD, F. (1936) The tin deposits of Llallagua, Bolivia (disc.). *Economic Geology*, **31**, 219–221.

AHLFELD, F. (1941) *Los Yacimientos Minerales de Bolivia.* Dirección General de Minas y Petróleos, La Paz, 94–100.

AHLFELD, F. (1941) Zoning in the Bolivian tin belt. *Economic Geology*, **36**, 569–588.

AHLFELD, F. (1954) *Los Yacimientos Minerales de Bolivia.* El Banco Minero de Bolivia y la Corporación Minera de Bolivia, 2nd edition, Bilbao, 63–67.

AHLFELD, F., and MUÑOZ REYES, J. (1955) *Las Especies Minerales de Bolivia*. Banco Minero de Bolivia, La Paz, Bolivia. 180 p.

AHLFELD, F., and SCHNEIDER-SCHERBINA, A. (1964) *Los Yacimientos Minerales y Hidrocarburos de Bolivia*. Departamento National de Geologia, Bolivia, Boletin 5, 388 p.

ANTHONY, J. W., BIDEAUX, R. A., BLADH, K. W., and NICHOLS, M. C. (1997) *Handbook of Mineralogy. Vol. III: Halides, Hydroxides, Oxides.* Mineral Data Publishing, Tucson, 278.

ARZRUNI, I. (1884) Ueber einige Mineralien aus Bolivia. *Zeitschrift für Krystallographie*, **9**, 73.

BANDY, M. C. (1944) *Mineralogy of Llallagua, Bolivia.* La Paz (reprinted by Tucson Gem and Mineral Society in 1976 as "Special Publication No. 1"). Available from the Natural History Museum of Los Angeles County; see page 190 for contact information.

CLARK, A. M. (1993) *Hey's Mineral Index.* Chapman and Hall, London, 405.

DAVY, W. M. (1920) Ore deposition in the Bolivian tin-silver deposits. *Economic Geology*, **15**, 463–496.

DERINGER, D. C., and PAYNE, J. Jr. (1937) Patino, leading producer of tin: I. The ore deposits of Llallagua. *Engineering and Mining Journal*, **138**, 171–177, 232–238.

FRONDEL, C. (1958) Systematic Mineralogy of Uranium and Thorium. *USGS Bulletin* **1064**, p 275.

GORDON, S. G. (1923) Vauxite and Paravauxite, two new minerals from Llallagua, Bolivia. *Proceedings of the Academy of Natural Science, Philadelphia,* **75**, 261–267.

GORDON, S. G. (1939) Thorium-free monazite from Llallagua, Bolivia. *Academy of Natural Science, Philadelphia, Notulae Naturae,* no. 2.

GORDON, S. G. (1944) The mineralogy of the tin mines of Cerro de Llallagua, Bolivia. *Proceedings of the Academy of Natural Science, Philadelphia,* **96**, 279–359.

GREENE, G. U. (1943) Collecting minerals at Llallagua, Bolivia. *Rocks & Minerals,* **18**, 291–294.

HERZENBERG, R. (1933) Gumucionit, eine neue arsenhaltige Varietät der Schalenblende. *Centralblatt für Mineralogie A*, 77–78.

HURLBUT, C. S., and HONEA, R., (1962) Sigloite, a new mineral from Llallagua, Bolivia. *American Mineralogist,* **47**, 1–8.

HYRSL, J., and PETROV, A. (1996) Potosi und Oruro, die bedeutendsten Silberlagerstätten Boliviens. *Mineralien-Welt,* **7** (6), 36–49.

HYRSL, J., and PETROV, A. (1998) Pseudomorphs from Bolivia, A Review. *Rocks & Minerals,* **73** (6), 410–414.

JONES, R. W. (1973) The Mark Chance Bandy collection. *Mineralogical Record,* **4**, 277–281.

KAMPF, A. R., (1982) Jeanbandyite, a new member of the stottite group from Llallagua, Bolivia. *Mineralogical Record*, **13**, 235–239.

MONTGOMERY, A. (1973–1975) An American mineralogist [Sam Gordon]. *Mineralogical Record,* **4**, 256–261; **5**, 34–39; **5**, 59–66; **5**, 115–127; **5**, 160–166; **5**, 211–214; **5**, 257–264; **6**, 7–12; **6**, 57–61.

MOON, L. (1939) Structural geology at Llallagua, Bolivia. *Minnesota Academy of Science, Proceedings*, **7**, 64–72.

PETROV, A., SMITH, B., and SMITH, C. (2001) A guide to mineral localities in Bolivia. *Mineralogical Record,* **32**, 457–482.

RAKOVAN, J. (2003) Exceptional apatites from the Siglo XX mine, Llallagua, Bolivia. *Mineralogical Record*, **34**, 1, 117.

RECHENBERG, H. P. (1955) Die Zinnseifenlagerstätte von Llallagua, Bolivien. *Berg- und Hüttenmännisches Monatshefte*, **100** (10), 280–284.

SAMOYLOFF, V. (1934) The Llallagua-Uncía tin deposit. *Economic Geology*, **29**, 481–499.

STELZNER, A. W. (1892) *Zeitschrift für deutschen geologische Gesellschaft*, **44**, 531–533.

STELZNER, A. W. (1897) *Zeitschrift für deutschen geologische Gesellschaft*, **49**, 89 and 129.

TURNEAURE, F. S. (1935) The tin deposits of Llallagua, Bolivia. *Economic Geology*, **30**, 14–60, 170–190.

TURNEAURE, F. S. (1960) A comparative study of major ore deposits of central Bolivia. *Economic Geology*, **55**, Part I, 217–254 and Part II, 574–606.

YEATMAN & BERRY (1930) *The Mining Journal*, supplement, January 25, 41–44.

LAFOSSAITE

A NEW MINERAL FROM THE LA FOSSA CRATER VULCANO, ITALY

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ABSTRACT

Lafossaite, idealized formula TlCl, is cubic, space group *P-m3m* (by analogy with the synthetic inorganic equivalent) with unit-cell parameter refined from powder data: a = 3.8756(3) Å, V = 58.213(8) Å^3, Z = 1. The strongest six reflections in the X-ray powder-diffraction pattern are [d(Å)(I)(hkl)]: 3.887(80)(100); 2.745(100)(110); 2.237(55)(111); 1.937(50)(200); 1.733(45)(210); 1.583(70)(211). The mineral occurs on a single specimen (6 × 7 × 9 cm) collected from one of the active 400°C fumaroles on the rim of the La Fossa crater, island of Vulcano, Aeolian archipelago, Sicily, Italy, as a drusy coating on one surface. The mineral formed as a sublimate directly from fumarolic gas and is associated with a number of other sublimate minerals including cannizzarite, galenobismutite, pyrite and an undefined Fe-K-Si-bearing phase. Crystals do not exceed 0.2 mm in size and are euhedral to subhedral (predominant) cubes and octahedra which are tightly intergrown in some areas. Forms are {100} (smooth and lustrous) major, {111} (rough and non-lustrous) minor, and {110} (rough and non-lustrous) very minor. Lafossaite possesses the following physical properties: color is gray-brown (R.H.S. 199D); streak is off-white to cream (and resinous looking); luster is resinous to greasy; diaphaneity is translucent; non-fluorescent; Mohs hardness is estimated at 3–4; tenacity is malleable; fracture is subconchoidal; cleavage and parting are not evident; calculated density is 7.212 g/cm^3 (for empirical formula and unit-cell parameter refined from powder data). The mineral is yellow-brown in plane-polarized transmitted light, isotropic with no pleochroism, and $n \gg 1.8$. In plane-polarized reflected light, it is grayish-white, with white internal reflections and no evidence of anisotropy, bireflectance or pleochroism. The calculated index of refraction (589 nm) is 2.264. Reflectance values, in air and in oil, are tabulated. Averaged electron-microprobe analyses: Tl = 81.74, Cl = 10.79, Br = 5.99, total = 98.52 weight %, corresponding to $Tl_{1.03}(Cl_{0.78}Br_{0.19})_{\Sigma 0.97}$, based on 2 total atoms. The mineral is soluble in dilute HCl. The mineral name is for the locality.

INTRODUCTION

Lafossaite, ideally TlCl, is a newly recognized mineral species that was collected from an active fumerole in the La Fossa crater on the island of Vulcano, Italy. Preliminary energy-dispersion spectra (EDS) acquired with a scanning-electron microscope (SEM) strongly suggested that the mineral was new to science. Further study using modern mineralogical techniques has confirmed this supposition and the results are reported herein.

The mineral is named lafossaite after the locality, which is the current active volcanic crater on Vulcano. The mineral and mineral name have been approved by the Commission on New Minerals and Mineral Names, I.M.A. (2003-32). The holotype specimen is housed in the research collection of one of us (T.M.S.) at the Institut für Mineralogie und Petrographie (ETH Zürich), a portion (4 × 5 × 6 mm) of which has been deposited in the Systematic Reference Series of the National Mineral Collection of Canada, Geological Survey of Canada, Ottawa, under catalog number 68098. The polished section used for quantitative electron-microprobe analyses and reflectance studies is housed in the mineral collections at The Natural History Museum, London, UK, as BM2004,55.

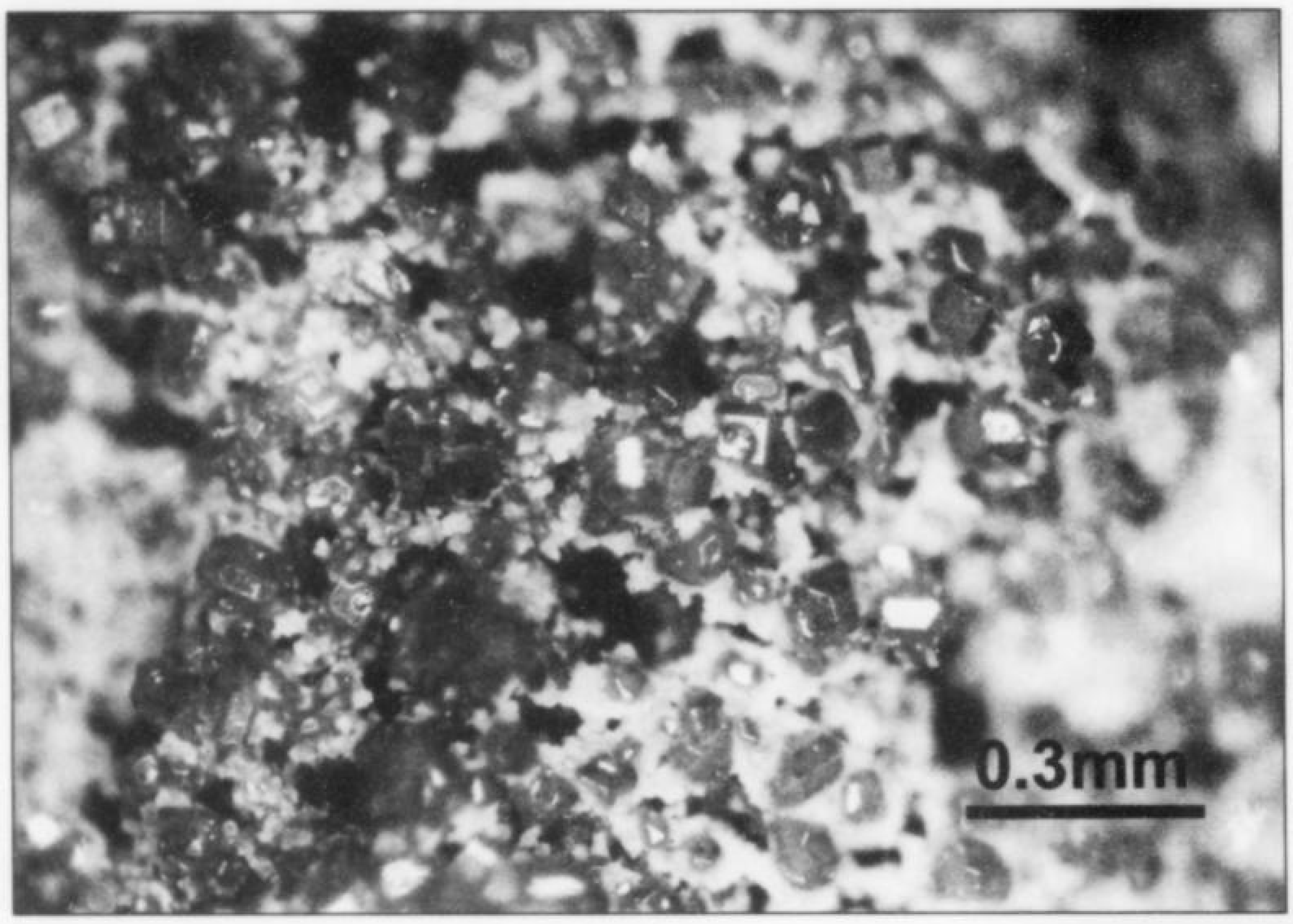
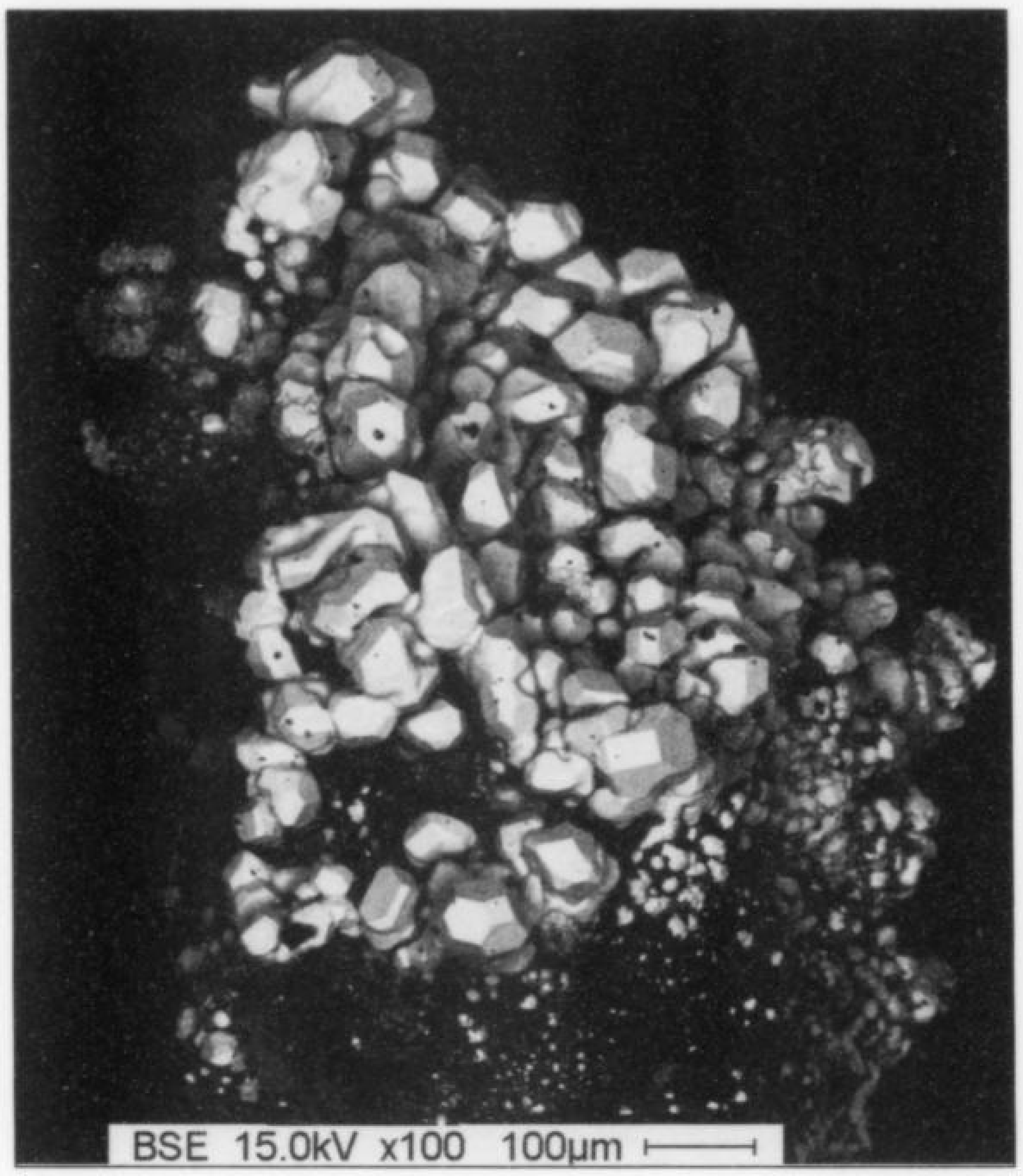


Figure 1. **Aggregates of subhedral to euhedral lafossaite crystals. Scale bar: 0.3 mm.**

Figure 2. **Euhedral lafossaite crystal aggregates. Scale bar: 100 µm.**



OCCURRENCE

Lafossaite occurs as a drusy coating of tiny crystals sporadically distributed over the irregular surface of a single sample (6 × 7 × 9 cm) comprised of fragments of partly altered (by fumarolic gases) ash and lapilli cemented together by other sublimate minerals (*i.e.*, silica, hieratite, sal ammoniac and other unidentified phases). It was collected by one of us (T.M.S.) in September 2001 from a 400°C fumarole on the rim of the La Fossa crater on the island of Vulcano, Aeolian archipelago, Sicily, Italy (latitude 38°23′ N, longitude 14°58′ E).

Associated sublimate phases are fine-grained pyrite and euhedral cannizzarite and galenobismutite crystals, many of which are coated by small lafossaite crystals. In addition, it is associated with a very fine-grained white opaque crust which is an intimate mixture of lafossaite and an undefined phase which shows (by SEM-EDS) variable Fe, K and Si. Typically, isolated lafossaite grains and aggregates are surrounded by this white mixture. Only one specimen has been found, despite an extensive search for further material. The mineral must be considered very rare.

The lafossaite sublimed at about 400°C from fumarolic gas containing appreciable concentrations of the halogen acids HF, HCl and HBr (Wahrenberger *et al.*, 2004). The gases discharging from the crater rim fumaroles contain up to 2.25 mg/kg of thallium and the dominant transport mechanism is considered to be the volatile molecular complex TlCl (Wahrenberger *et al.*, 2004). Cannizzarite and bismuthinite crystals from the crater rim fumaroles contain up to 200 and 2500 mg/kg of thallium, respectively. Bebié *et al.* (1998) have shown that the aquated Tl^{+} ion and TlCl(aq) may also play an important role in the transport of thallium in hydrothermal systems.

PHYSICAL PROPERTIES

Lafossaite single grains and aggregates occur as a crust (6 × 2.5 mm) on one surface of the type (NMCC) specimen (Fig. 1). Individual crystals form subhedral (predominant) to euhedral cubes and octahedra (which may be tightly intergrown in some areas) that do not exceed 0.2 mm in size and tend to average a little less in most cases (Fig. 2). Forms observed include {100} major (face is smooth and lustrous and brightly reflecting under binocular light), {111} minor and {110} very minor (both of these forms have rougher non-lustrous faces which do not reflect under binocular light). The mineral is gray-brown (close to R.H.S. 199D) and the streak is off-white to cream (and resinous looking). It should be mentioned that grains do not "powder" in the conventional sense of the word; they flatten out or "squish" into a very thin sheet when pressed between two frosted glass slides. This characteristic makes X-ray powder-mount sample preparation rather difficult (but not impossible). The luster is resinous to greasy and the crystals are translucent. Lafossaite is malleable with a subconchoidal fracture, no observable cleavage or parting, and is non-fluorescent under both longwave and shortwave ultraviolet light. The hardness (Mohs') is estimated to be 3–4. The density could not be measured because of the small size of available crystals and dearth of material. The calculated density, on the basis of the empirical formula and unit-cell parameter refined from powder data, is 7.212 g/cm^3.

X-RAY STUDIES

A crystal of lafossaite, mounted with a^* parallel to the dial axis was examined by single-crystal precession methods with Zr-filtered Mo X-radiation. The following levels were photographed: $hk0$, hkl and $a^* \wedge 011^*$. The mineral is cubic, a = 3.901 Å, with no systematic space-group extinctions and $m3m$ diffraction symmetry. The space group is assumed to be P-$m3m$ (221) by analogy with the synthetic inorganic equivalent compound (see below). The refined unit-cell parameter from powder data: a = 3.8756(3) Å, V = 58.212(8) $Å^3$, Z = 1, is based on all 11 reflections with d values between 3.887 and 1.119 Å for which unambiguous indexing was possible, based on visual inspection of single-crystal precession films. A fully indexed powder pattern is presented in Table 1. These data are virtually identical to PDF 78-625 which is the calculated powder pattern for $Tl(Cl_{0.78}Br_{0.22})$ (Popova *et al.*, 1966) and, somewhat surprisingly, to sal ammoniac, NH_4Cl (PDF 7-7), which is isostructural with lafossaite. Both minerals are products of fumarolic activity and sal ammoniac has also been identified on Vulcano. Thus, while routine X-ray powder-diffraction studies will not reliably differentiate between the two mineral species, it will narrow down the choices to one or the other, and allow qualitative chemistry (routine EDS on a SEM) to differentiate between the two. The experimental powder data for end-member synthetic TlCl is given in PDF 6-486; this data should be added to the Mineral File of the PDF and named "lafossaite, syn."

***Table 1.* X-ray powder-diffraction data for lafossaite.**

	$I_{est.}$	$dÅ_{meas.}$	$dÅ_{calc.}$	hkl
*	80	3.887	3.876	100
*	100	2.745	2.740	110
*	55	2.237	2.238	111
*	50	1.937	1.938	200
*	45	1.733	1.733	210
*	70	1.583	1.582	211
*	25	1.370	1.370	220
*	20	1.291	1.292	300
			1.292	221
*	25	1.226	1.226	310
*	10	1.169	1.169	311
*	15	1.119	1.119	222

- 114.6 mm Debye-Scherrer powder camera; Cu radiation, Ni-filter ($\lambda CuK\alpha$ = 1.54178 Å).
- Intensities estimated visually; * = lines used for unit-cell refinement.
- Corrected for shrinkage and no internal standard.
- Indexed on a = 3.8756 Å.

CRYSTAL STRUCTURE

The crystal structure of the synthetic inorganic equivalent of lafossaite is very well known and was first successfully solved over eighty years ago by Davey and Wick (1921). Since then, the TlCl structure has been studied by a number of researchers (Swanson *et al.*, 1955 and references therein), most recently by Smakula and Kalnajs (1955) (PDF calculated pattern 89-4255) and by Popova *et al.* (1966) (PDF calculated patterns 78-623 to 78-627). The structure belongs to the CsCl-type and consists of a framework of face-sharing hexahedra with Tl at 0, 0, 0 and Cl(Br) at ½, ½, ½. The Pearson Symbol Code (PSC) is $cP2$. Popova *et al.* (1966) also studied the crystallographic effects of Br substitution for Cl within the structure.

CHEMISTRY

Several lafossaite crystals were analyzed with a Cameca SX-50 electron microprobe utilizing an operating voltage of 10 kV, a beam current of 10 nA, and a beam diameter of 5 µm. Data were ZAF corrected and count times were 10s on peak and 5s on background. Synthetic Tl(Br,I) (for Tl and Br) and synthetic KCl (for Cl) were used as appropriate standards. A 100s energy-dispersion scan showed no elements other than those reported. I, K and Na were sought but not detected. The average of fourteen determinations are given in Table 2 and the empirical formula (based on total atoms = 2) for lafossaite is $Tl_{1.03}(Cl_{0.78}Br_{0.19})_{\Sigma 0.97}$. The idealized formula, TlCl, requires Tl = 85.22, Cl = 14.78, total = 100.00 weight % and the formula $Tl(Cl_{0.8}Br_{0.2})_{\Sigma 1.0}$, requires Tl = 82.17, Cl = 11.40, Br = 6.42, total = 100.00 weight %. The mineral is insoluble in cold H_2O and somewhat soluble in dilute HCl. Lafossaite is the first naturally occurring Tl-bearing halide and is the second member of the sal ammoniac group (Strunz classification 3.AA.25). It has been previously reported (as unnamed TlCl) by Gorshkov *et al.* (1998) as 1-12 µm-sized equant particles within diamondiferous kimberlite rock at the Udachnaya pipe, Yakutia, Russia.

***Table 2.* Compositional data for lafossaite.**

	Atomic Weight %	*Range*	*Standard Deviation*
Tl	81.74	79.95 - 84.00	1.49
Cl	10.79	9.77 - 11.63	0.57
Br	5.99	5.49 - 6.34	0.28
Total	98.52		1.75

OPTICAL PROPERTIES

A grain mount, with a Na-gel filtered light (590 nm), shows that lafossaite is yellow-brown in plane-polarized transmitted light, isotropic, and displays no pleochroism. The index of refraction is ⩾ 1.80 and could not be accurately measured with the available immersion oils.

In plane-polarized reflected light (~3200° K), lafossaite is grayish-white with distinct white internal reflections. There is no evidence of anisotropy, bireflectance, nor pleochroism. Reflectance measurements were made in the visible region (400-700 nm) at intervals of 20 µm using a Leitz MPV-SP microscope-spectrophotometer. A WTiC reflectance standard (Zeiss 314) was used as a reference for air and oil (Leica N_D = 1.518) measurements. These were done with 20 X objectives, the numerical apertures of which were confined to 0.40, and the diameter of the measured disks was 9 µm. The reflectance curve (R) descends continuously from short

***Table 3.* Reflectance data for lafossaite.**

λnm	*R*	*^{im}R*	*λnm*	*R*	*^{im}R*
400	17.7	5.4	560	15.1	3.9
420	16.8	5.0	580	15.0	3.9
440	16.5	4.7	589 (COM)	15.0	4.0
460	16.2	4.5	600	14.9	3.9
470 (COM)	16.0	4.4	620	14.8	3.9
480	15.8	4.4	640	14.8	3.8
500	15.6	4.2	650 (COM)	14.7	3.8
520	15.4	4.1	660	14.7	3.8
540	15.2	4.1	680	14.6	3.8
546 (COM)	15.2	4.0	700	14.6	3.8

to long wavelength. In Table 3, we summarize the data collected from the only grain available in polished section. The values may be slightly low because the grain surface is scratched and not well polished. For 589 nm, the calculated index of refraction is 2.264.

ACKNOWLEDGMENTS

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REFERENCES

BEBIÉ, J., SEWARD, T. M., and HOVEY, J. K. (1998) Spectrophotometric determination of the stability of thallium (I) chloride complexes in aqueous solutions up to 200°C. *Geochemica Cosmochimica Acta*, **62**, 1643–1651.

DAVEY, W. P., and WICK, F. G. (1921) The crystal structure of two rare halogen salts. *Physical Review*, **17**, 403–404.

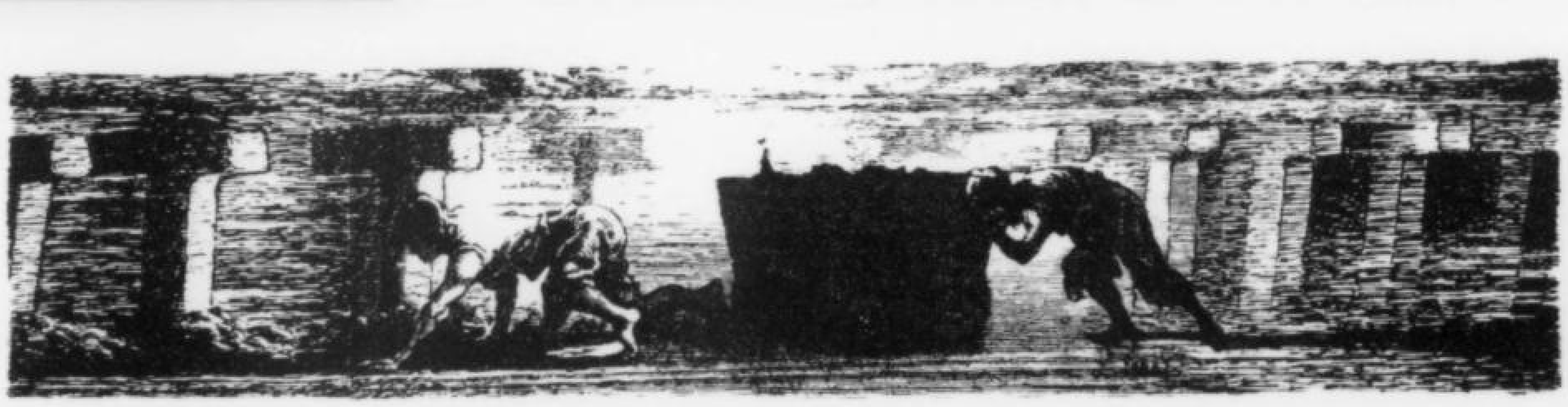
GORSHKOV, A. I., VINOKUROV, S. F., SOLODOV, D. I., BERSHOV, L. V., MOKHOV, A. V., SOLODOVA, Yu. P., and SIVTSOV, A. V. (1998) Polycrystalline Diamond from the Udachnaya Pipe, Yakutia: Mineralogical, Geochemical, and Genetic Characteristics. *Lithology and Mineral Resources*, **33**, 525–538.

POPOVA, M. A., DARVOJD, T. J., and GURVICH, M. A. (1966) Changes of the period of lattice and microhardness of the homogeneous solid solutions TlBr - TlCl. *Zhurnal Neorganicheskoi Khimii*, **11**, 1236–1238 (in Russian).

SMAKULA, A., and KALNAJS, J. (1955) Precision Determination of Lattice Constants with a Geiger-Counter X-Ray Diffractometer. *Physical Review*, **99**, 1737–1743.

SWANSON, H. E., FUYAT, R. K., and UGRINIC, G. M. (1955) Thallium Chloride, TlCl (cubic). Standard X-ray Diffraction Powder Patterns. *National Bureau of Standards Circular 539*, **4**, 51–52.

WAHRENBERGER, C. M., SEWARD, T. M., and DIETRICH, V. (2004) The chemistry of volcanic gases at La Fossa crater, Vulcano, Aeolian Islands (Italy). (submitted).



Collector Profile:

Richard W. Graeme
And the Graeme Family Collection of Bisbee Minerals and Ores

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Richard W. ("Dick") Graeme and his twin sons Richard IV and Douglas have assembled what is probably the world's most comprehensive collection of mineral specimens and ore samples from the great Bisbee, Arizona copper districts, including both display and reference sub-collections. The family connection with Bisbee goes back to 1883, when Dick's grandfather first worked as a miner there and began collecting specimens. Though living mostly abroad these days, Dick continues, with the help of his sons, to build the Bisbee collection and to record precious data on Bisbee history and mineralogy.

INTRODUCTION

The September-October 1981 issue of *The Mineralogical Record* has a one-word, one-punctuation-mark title that sings of promise to the knowledgeable: *Bisbee!* This thorough account of the great mining district and its minerals was written entirely by Richard W. Graeme (pronounced "Graham"), born in Bisbee, once a worker in the mines there, and eponym of the extremely rare Bisbee species *graemite*.

Mineralogical Record readers next heard from Dick Graeme in the November-December 1993 issue, wherein he offered an update: 285 Bisbee species had by then become known, and Dick and his sons had collected the type specimens of many of them. Today he is still not finished monitoring and chronicling the locality, and there is no one better qualified for the job, as a lifetime's worth of digging and dealing has yielded Dick and his two sons what is surely the most comprehensive collection of display specimens from Bisbee, as well as the most exhaustive Bisbee reference collection, on Earth. Both collections reside in the basement of Dick's spacious home on the north side of Tucson, where his daughter lives year-round. Dick, however, is in residence only a few weeks out of each year, since his job as a mining consultant keeps him overseas the rest of the time; currently he works in Peru. But no amount of living in foreign climes and working with foreign mineral deposits seems likely ever to dampen Dick's devotion to Bisbee; indeed, he is of his family's third generation, and his sons of the fourth, to know this devotion. A little family history, then, for a start:

A BISBEE LIFE

Dick Graeme's maternal grandfather arrived in Bisbee in 1883, when rich ore already was being taken in quantity from the Copper Queen, the earliest of the district's mines. Twenty years before, the pioneer family of Mormons had crossed the Great Plains from the East, and now Dick's grandfather, though just a boy, had tired of farming, and with his family he was seeking new opportunities somewhere along the route between Utah and Mexico. In Bisbee he

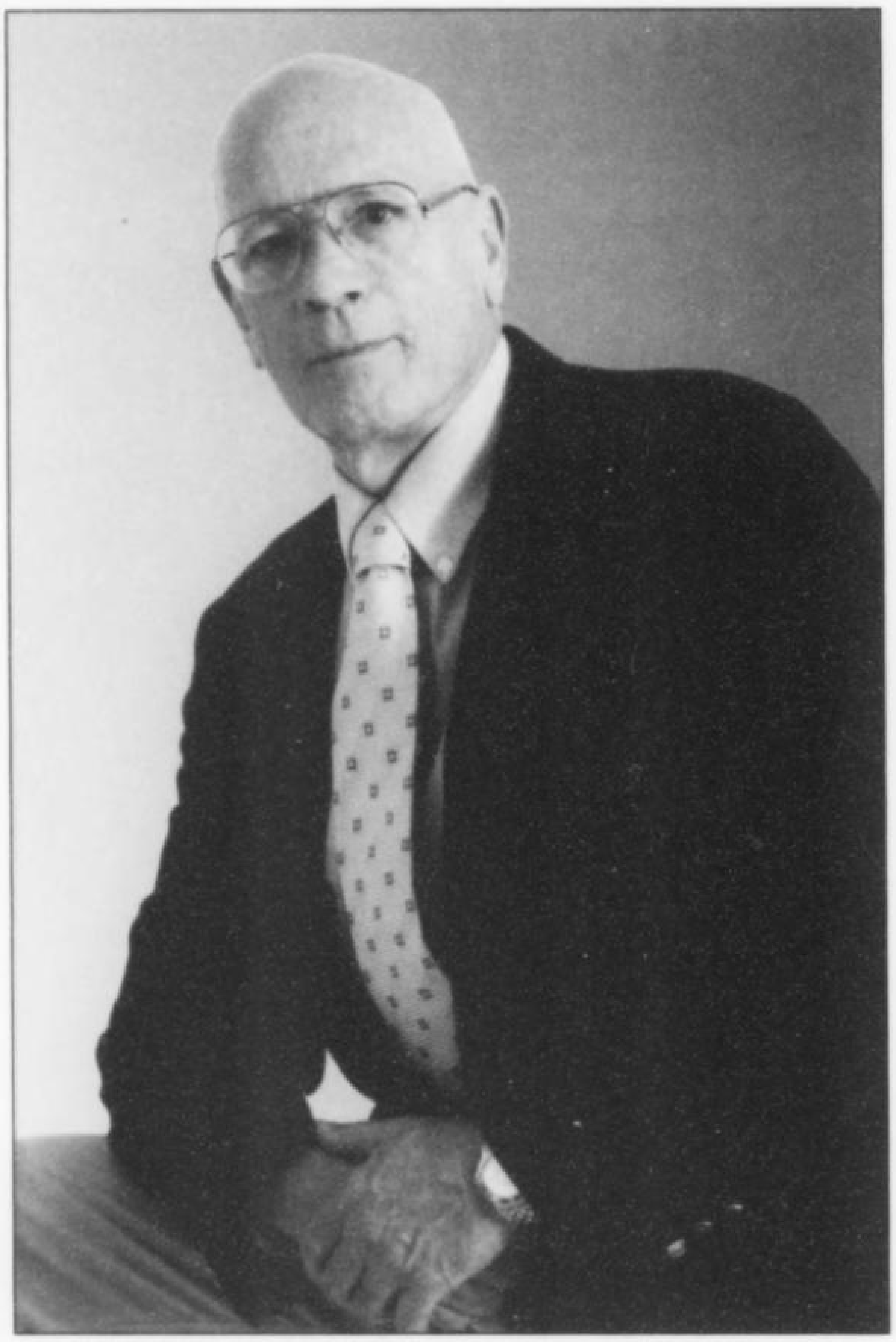


Figure 1. **Richard W. Graeme III.**

quickly found work as a miner, loved it and profited by it, and decided to stay.

Well crystallized minerals, it seems, "spoke" to Dick's grandfather, and he often smuggled them out of the mines in his lunchbox. At home they passed in a regular stream from the lunchbox to Grandmother's flower garden outside: she didn't need any more things to clean, she said. A few favored specimens, however, secured asylum in the family's china cabinet: the oldest piece in Dick's collection today is an azurite brought home by his grandfather sometime around 1890.

When Dick was born in 1941 his grandfather was still working as a "powder monkey" in the Bisbee mines, although he had long since sold off almost all of his specimens. (Dick's father was a Bisbee miner too, until just after World War II, though he was never interested in minerals, and left Bisbee in the late 1940's.) After retiring in 1948, Grandfather had plenty of time to tell stories about life and work in the mines. Abandoned mine entrances could be seen from just about any vantage in town, and Dick was only about six when he began to venture alone, with candles, into them. When an old miner gave him a carbide lamp (with appropriate stern warnings), his explorations expanded considerably: he collected mineral specimens throughout the 1950's, in countless forays through hundreds of miles of mine workings. In the Cole shaft in 1959, when he was 17, he found a specimen with some peculiar-looking green stuff that proved to be a species new to science, and would eventually be described as the hydrated copper tellurite *graemite* (Williams and Matter, 1975).

Following graduation from Bisbee High School in 1960, Dick went to work at the Campbell mine as a mucker, working full-time at shoveling mud from drainage ditches to keep the haulage track clean. Over time he worked his way to better jobs, becoming eventually a full-fledged underground miner. In 1964, feeling the need to professionalize, he began commuting to Tucson to take University of Arizona courses, while at the mines meanwhile he managed somehow to work a regular graveyard shift, 11:00 p.m. to 7:00 a.m. It was during this period, too, that he married and started a family—although, he observes today, his wife Nina and little girl Jennifer seldom saw him awake. In 1968 his twin sons, Richard IV and Douglas, were born.

Dick received his University of Arizona B.S. degree in Geological Engineering in 1972, and soon thereafter became Resident Geologist for the Copper Queen branch of the Phelps-Dodge Corporation at Bisbee. Taking this job meant a big pay cut, but the sacrifice seemed at least bearable, since one of his new duties was to collect crystallized minerals ahead of mining, especially in the Lavender Pit mine, then very prolific of specimens. The dream job, in other words, was a function of the enlightened attitude of Phelps-Dodge: the corporation donated many specimens Dick had collected to major museums, and sold others locally (including some to Dick) at its company store.

Unfortunately, though, the life of Bisbee as a producing mining camp was nearing its end. In mid-1975, after nearly a century of operation, the last of the mines closed for good, and Dick and his family had to move on. Phelps-Dodge transferred him to its huge copper mine at Ajo, where he became an administrative foreman. He lived in Ajo until 1979; his fourth and last child, Cherry Anne, was born there, but the downside for Dick was that from the mid-1970's he would work only in mine management, never again as an underground miner, engineer or geologist. Still, when in 1979 Dick left Phelps-Dodge entirely it felt, he says today, more like a sad divorce than just a job change—now, after almost a century, no one in the family worked for the company which meanwhile had gained the affectionate esteem of all the Graemes.

Next came a move to Hanover, New Mexico, and a job as a General Manager for the Sharon Steel Corporation; this company sent him also to work as General Manager of a coal mine in Utah and on floating gold dredges on rivers inland from Nome, Alaska. In 1985 he signed up with Gold Fields Ltd. to manage gold mines in New Mexico and southern California. In 1988 he began his own consulting business, specializing in mine startups in the United States, Chile, Bolivia, Argentina and Mexico. In 1999 Gold Fields called on him to go to revive an old gold mine in Ghana (the ex-British colony once called the "Gold Coast"), and he lived there for the great bulk of the time until November 2003. Currently he lives, for all but three weeks of the year, near a gold mine he helps to run in Cajamarca Province, Peru, 600 kilometers north of Lima. Dick feels a humanitarian satisfaction at having worked so long at developing mines in Africa and Latin America, thus helping to bring hope and opportunity to some of the world's poorest people. But through all his expatriate years he has maintained residences both in Tucson and Bisbee, and wouldn't think of spending his scant "free" weeks each year in any other places.

Though not without crises and strain (inevitably, given such a career), Dick's family life has remained strong. His second wife, Monica, died in January 2005 of a chronic illness and after 18 years of mutually supportive marriage: she was an accomplished mineral photographer, and kept encouraging Dick to complete his various Bisbee projects. His two daughters also have been supportive, and his twin sons have been his constant collecting partners—Doug and Richard IV are just as much to be credited as he is, Dick insists, for the present excellence of the Bisbee collection. Both men are married, Richard with children and Doug without. Richard is now a 6th-grade science teacher at Sierra Vista Middle School in

Figure 2. **Several of the many storage units housing the Graeme collection in Tucson. Tom Moore photo.**

Figure 3. **A drawer of extraordinary Bisbee specimens. Tom Moore photo.**

Sierra Vista; Doug works as a park ranger and environmental monitor at Kartchner Caverns near Benson. Whenever Dick is in town, all three go out field collecting, as they have done ever since the boys could wield hammers—no, not even in their teen years, all three swear, did the twins ever grow perverse about minerals, or show anything but total enthusiasm for helping their father dig at Bisbee. Today's visitor to the Tucson house encounters a seamlessly working, interdependent and loving, three-man team which hauls out the heavy drawers of spectacular specimens, one by one, from their gray steel and dark wooden cabinets . . .

THE COLLECTION

Actually, the big display which will awe visitors immediately as they enter the house is not yet in place: the major display pieces will go into four ceiling-high, glass-fronted cases in the living room, facing the front door. The Graemes have now nearly finished the job of constructing these cases (and two smaller cases of filing drawers) from carved wood panels and beams they recovered from an old private railroad car in Fierro, New Mexico in 1979. For now the Bisbee collection is housed in a basement room, just off a long corridor which is completely and impressively lined with bookcases: this is a library of about 11,000 books, professional papers, photographs, documents, etc., all related to mining at Bisbee and in Arizona and the western U.S. generally. On one area of open shelving there are 11 beautifully restored assaying scales, the remains of a collection of antique mining-related instruments which once was much larger.

The mineral collection is kept in a room that looks likewise erudite, with a large bookcase full of mineralogical literature filling most of a wall. The collection consists *only* of Bisbee specimens, and has two parts: a display collection of about 350 exhibit-quality pieces, and a reference collection with nearly 3,000 specimens, as well as some 2,000 pieces still awaiting complete study and/or cataloguing. Nearly 70% of both accumulations were field-collected at Bisbee by the Graemes, although new additions these days are largely made through purchase or exchange.

The reference collection is surely the world's most comprehensive and authoritative specimen base for students of Bisbee mineralogy. This unique and irreplaceable repository fills 70 wide pull-out drawers in eight head-high steel filing cabinets, plus about 20

Figure 4. **Copper with cuprite, 10.8 cm, from the Czar mine, Bisbee, Arizona. Graeme collection; Jeff Scovil photo.**

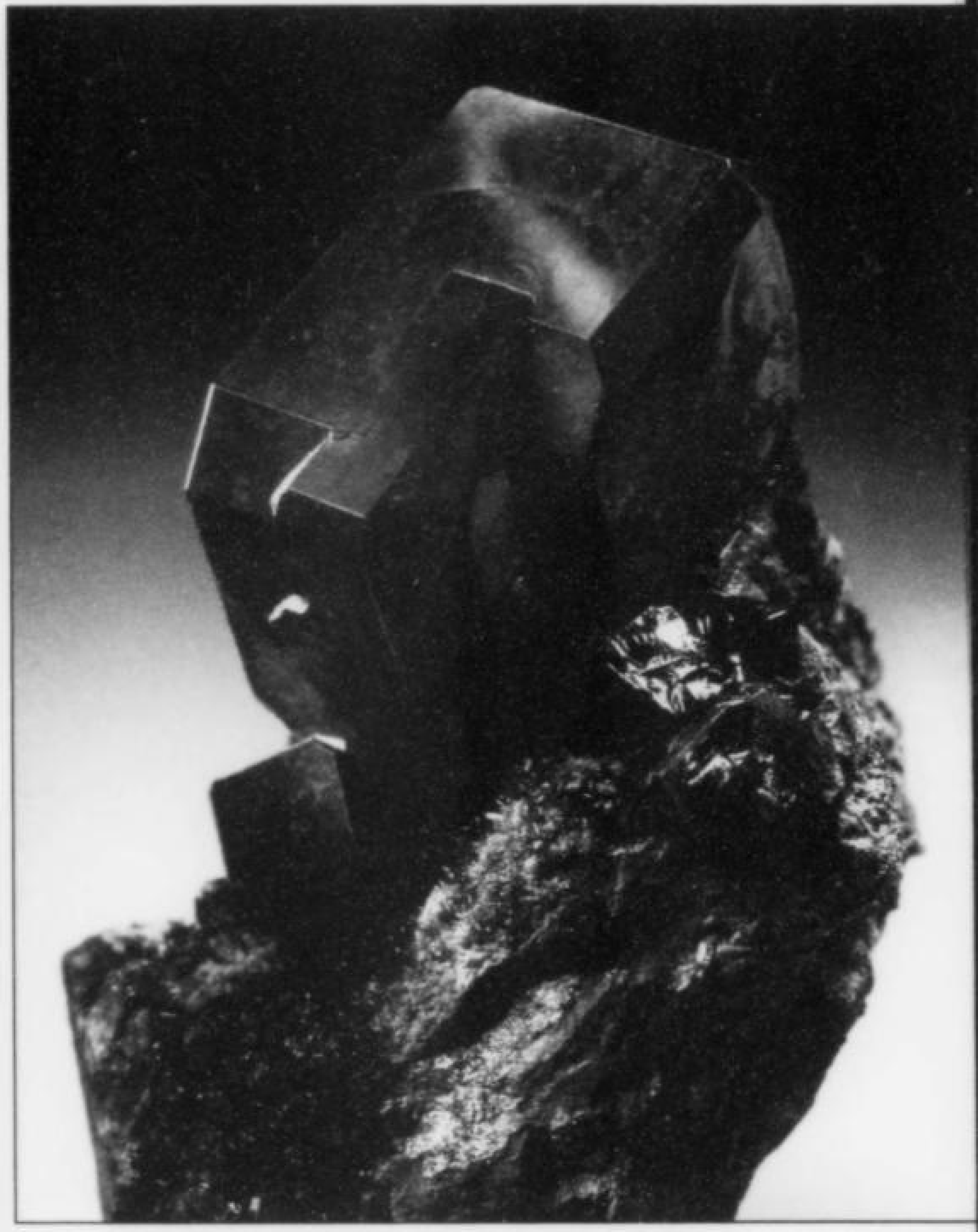


Figure 5. **Cuprite crystal, 2.6 cm, on brochantite, from the Southwest mine, Bisbee, Arizona. Graeme collection; Wendell Wilson photo.**

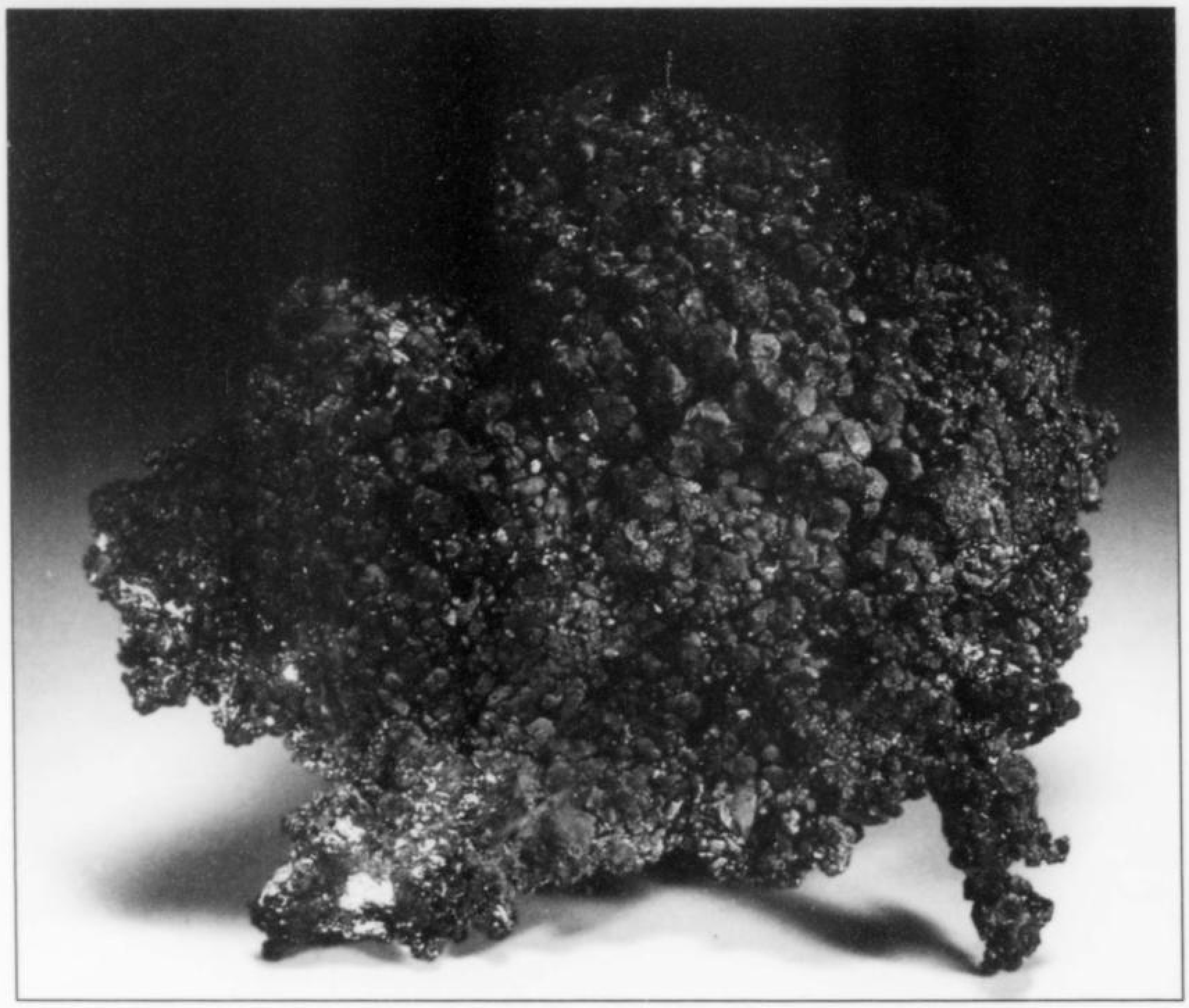


Figure 6. **Copper, 23.2 cm, from the Dallas mine, Bisbee, Arizona. Graeme collection; Jeff Scovil photo.**

more drawers in a wooden cabinet which the Graemes reserve for the prettier specimens of secondary copper species. The collection currently includes representatives of 195 of the 322 mineral species known from Bisbee, not counting what Dick calls the "microdots on goop" which are still awaiting study. Determinative work on these specimens continues to be carried out by professional mineralogists working with Dick, primarily at the University of Arizona, where mineral curator Shirley Wetmore has been extremely helpful. Much earlier determinative work, including the research on graemite, was done by Dick's good friend Sidney

Figure 7. **Cuprite crystals on copper, 8.4 cm, from the Dallas mine, Bisbee, Arizona. Graeme collection; Wendell Wilson photo.**

Figure 8. **Calcite included by cuprite, 10 cm (area shown), from the Czar mine, Bisbee, Arizona. Graeme collection; Jeff Scovil photo.**

Williams, formerly a Phelps-Dodge employee and independent mining consultant.

Meanwhile, Dick exhaustively documents the reference collection on his computer, preserving detailed information about each discovery, its site in the mines, and the relevant paragenesis. He is working on what will be a large book (or CD?) organizing all data on Bisbee species, and is currently investigating options for publication, both digital and hardcopy. In still another project, Dick and his sons are collaborating to write an in-depth history of mining at Bisbee, with attention to the "art" of mining from many different perspectives. This project, though, is still probably several years from completion.

Fun though it is to inspect the 100 or so drawers full of mostly massive and microcrystallized reference specimens, the visitor's real treat is, of course, to ogle the 350 or so superlative specimens in the display collection—all the while hearing running narratives of collecting adventures, and just *where* and *when* and *how* the Graemes won each beautiful piece from the various rich and complex Bisbee deposits.

The specimens range in size from large-thumbnail through large-cabinet, with every major Bisbee species present in a wide range of varieties and habits. Calcite and aragonite are here in profusion, twisting in great snow-white helixes, ram's-horns, and coralloidal shapes; aragonite makes pristine sprays of pointed, thin, transparent-colorless crystals; calcite exhibits dozens of crystal forms, and composes brilliant bright red or lush green (cuprite or malachite-included) crystal clusters. Native copper is to be seen as groups of sharp individual crystals; huge plates of dendritic aggregates; arabesque forms causing the viewer's eye to lose its way in confusion. Azurite is on hand as silken, bright blue botryoidal masses; sharply individualized, lustrous deep blue, spherical knots of crystals over wide expanses of matrix, with malachite flecks and microcrystals;

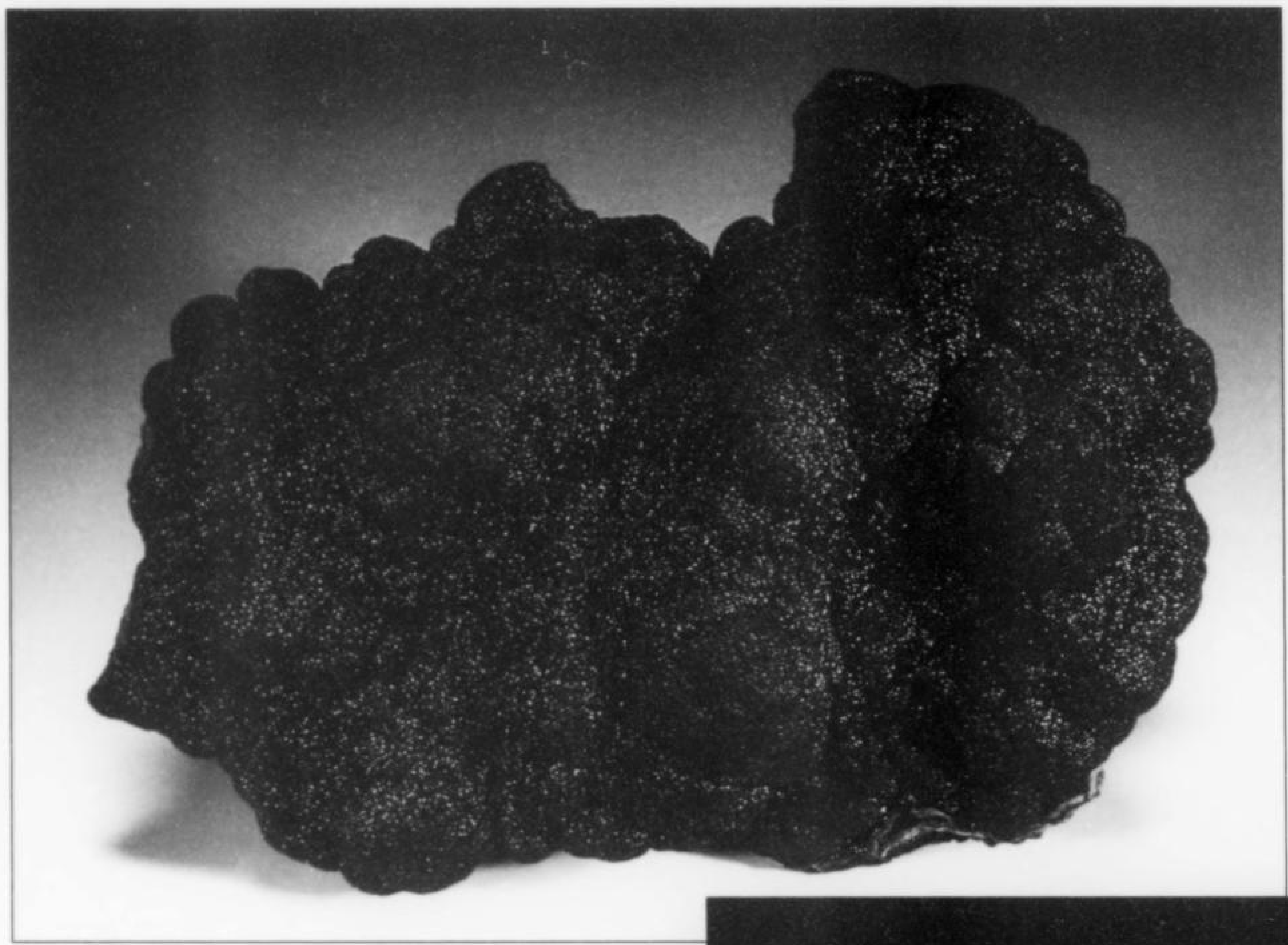
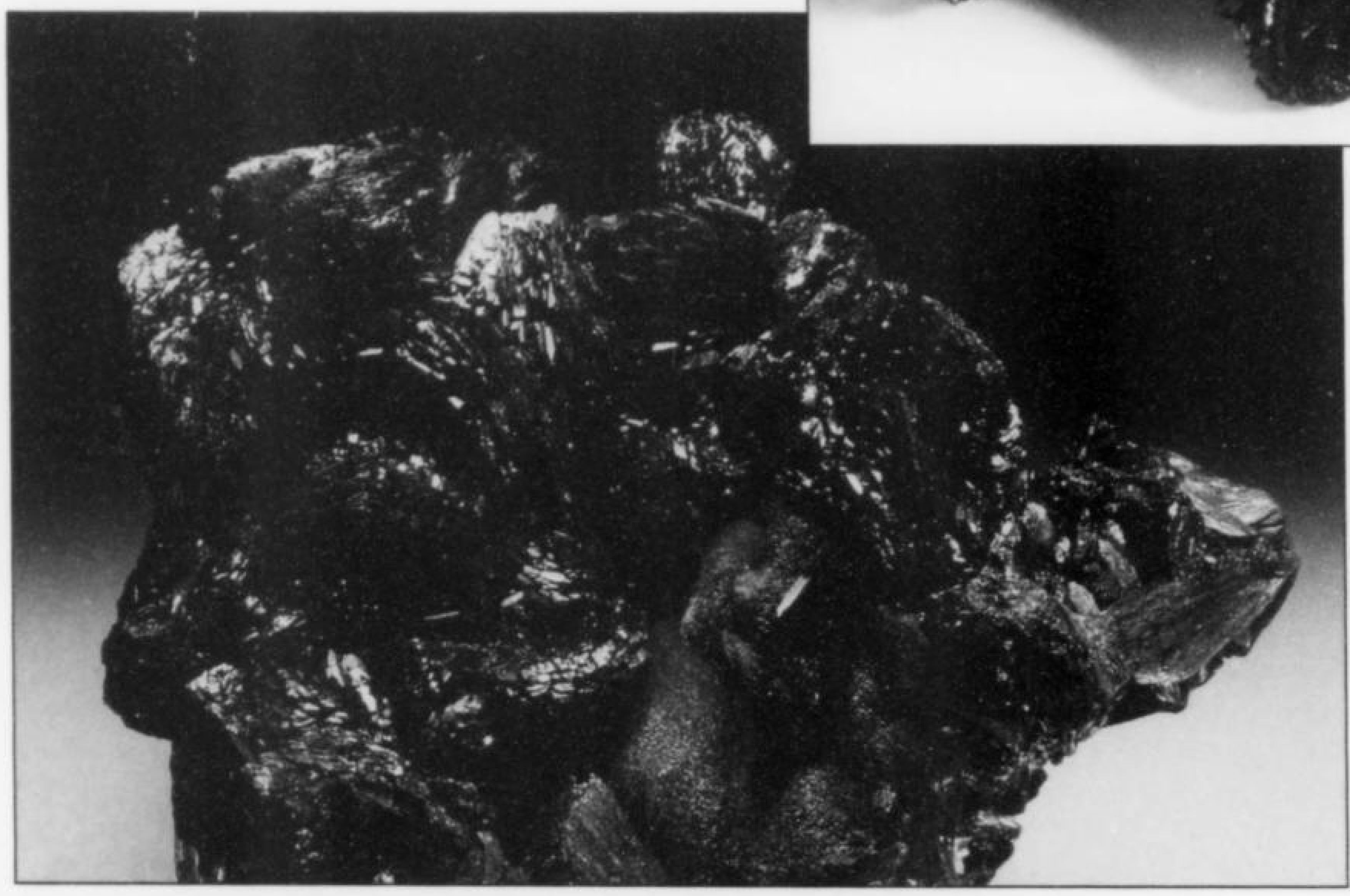


Figure 9. **Azurite, 25.8 cm, from Bisbee, Arizona. Graeme collection; Jeff Scovil photo.**

Figure 10. **Azurite, 21.3 cm, from the Copper Queen mine, Bisbee, Arizona. Graeme collection; Jeff Scovil photo.**

Figure 11. **Azurite crystals on malachite, 6 cm, from the Czar shaft, Bisbee, Arizona. Graeme collection; Wendell Wilson photo.**



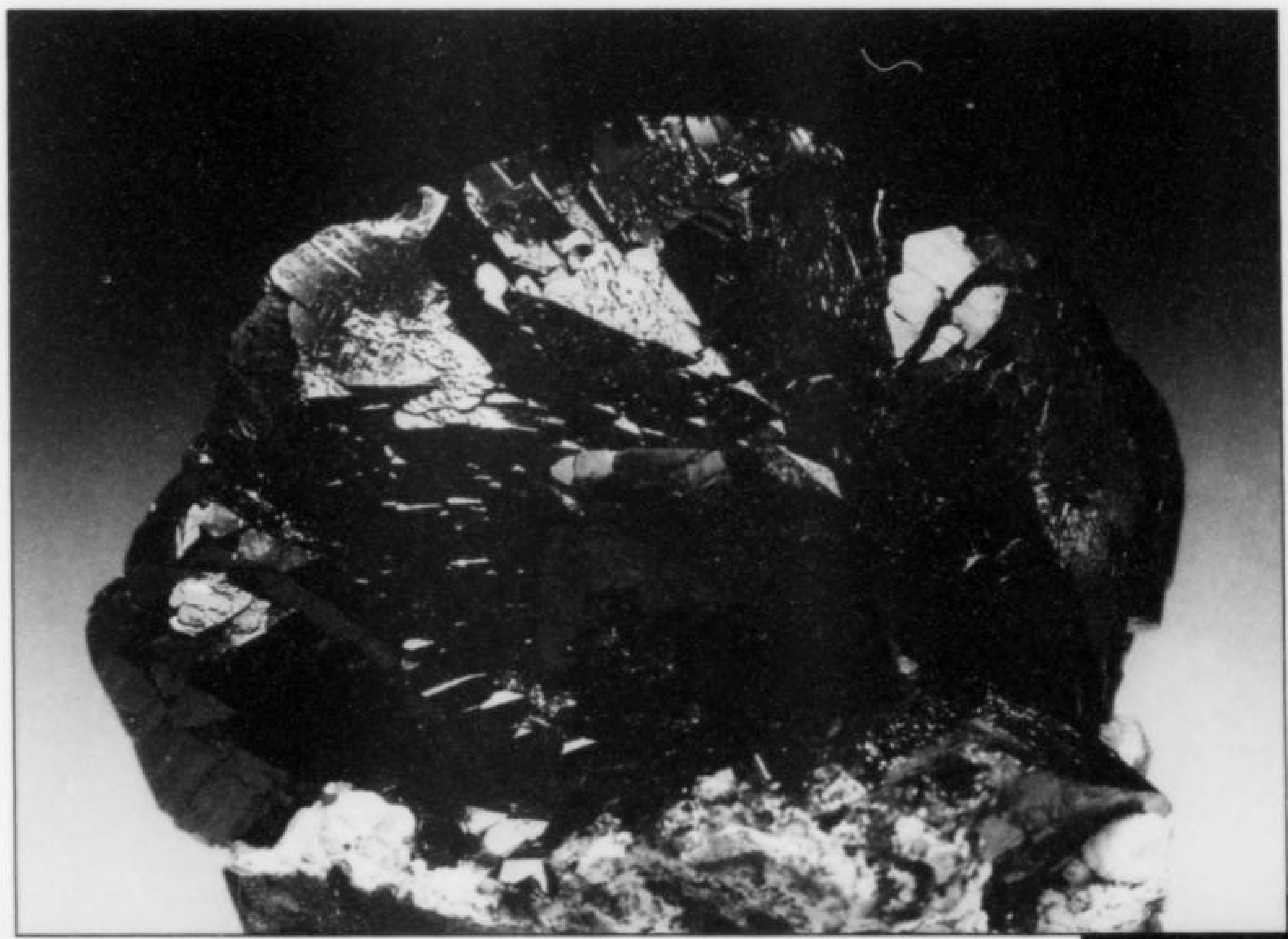
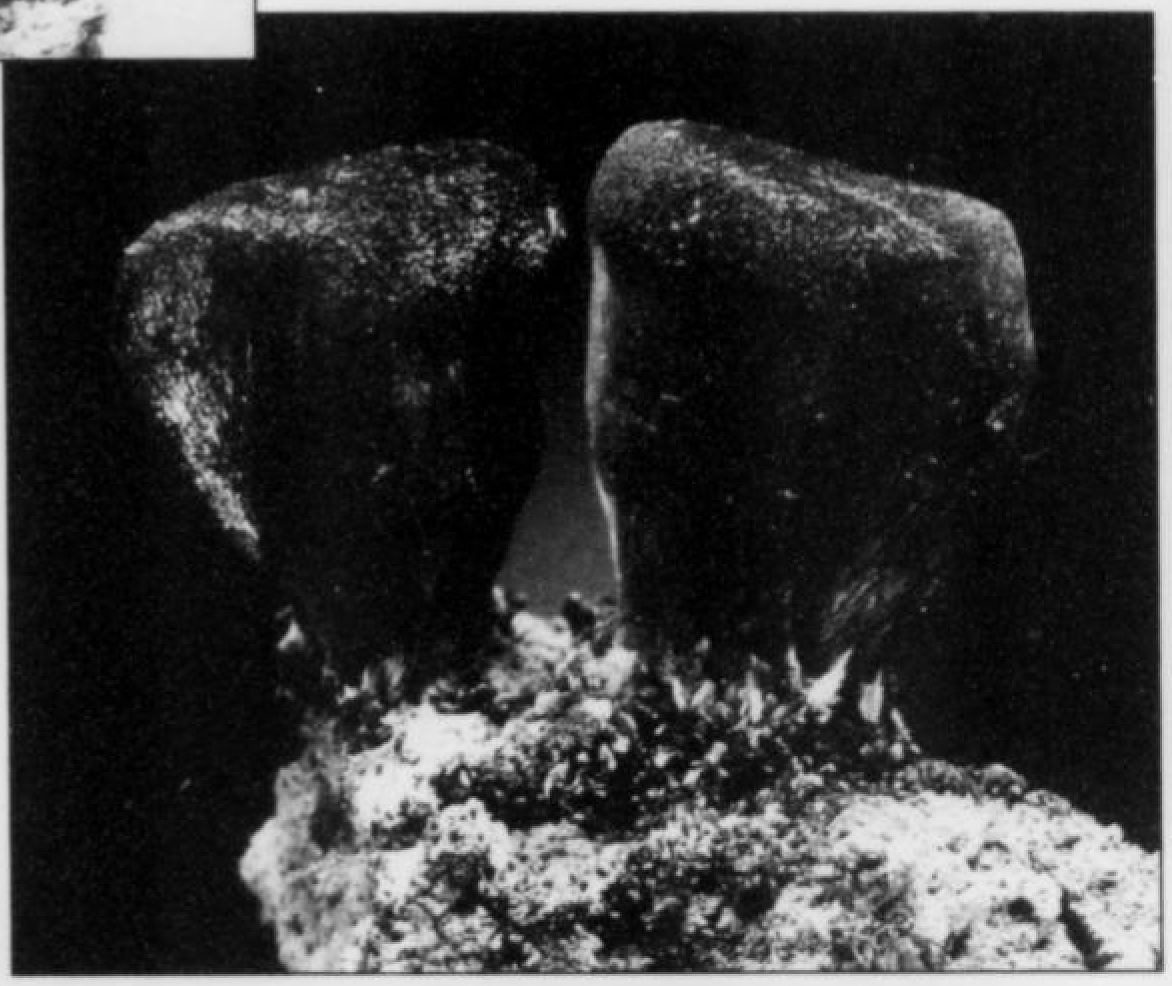


Figure 12. Azurite, 5.3 cm, from the Sacramento mine, Bisbee, Arizona. Graeme collection; Wendell Wilson photo.

Figure 13. Malachite, 3.1 cm, from the 800 level, Cole mine, Bisbee, Arizona. Graeme collection; Jeff Scovil photo.



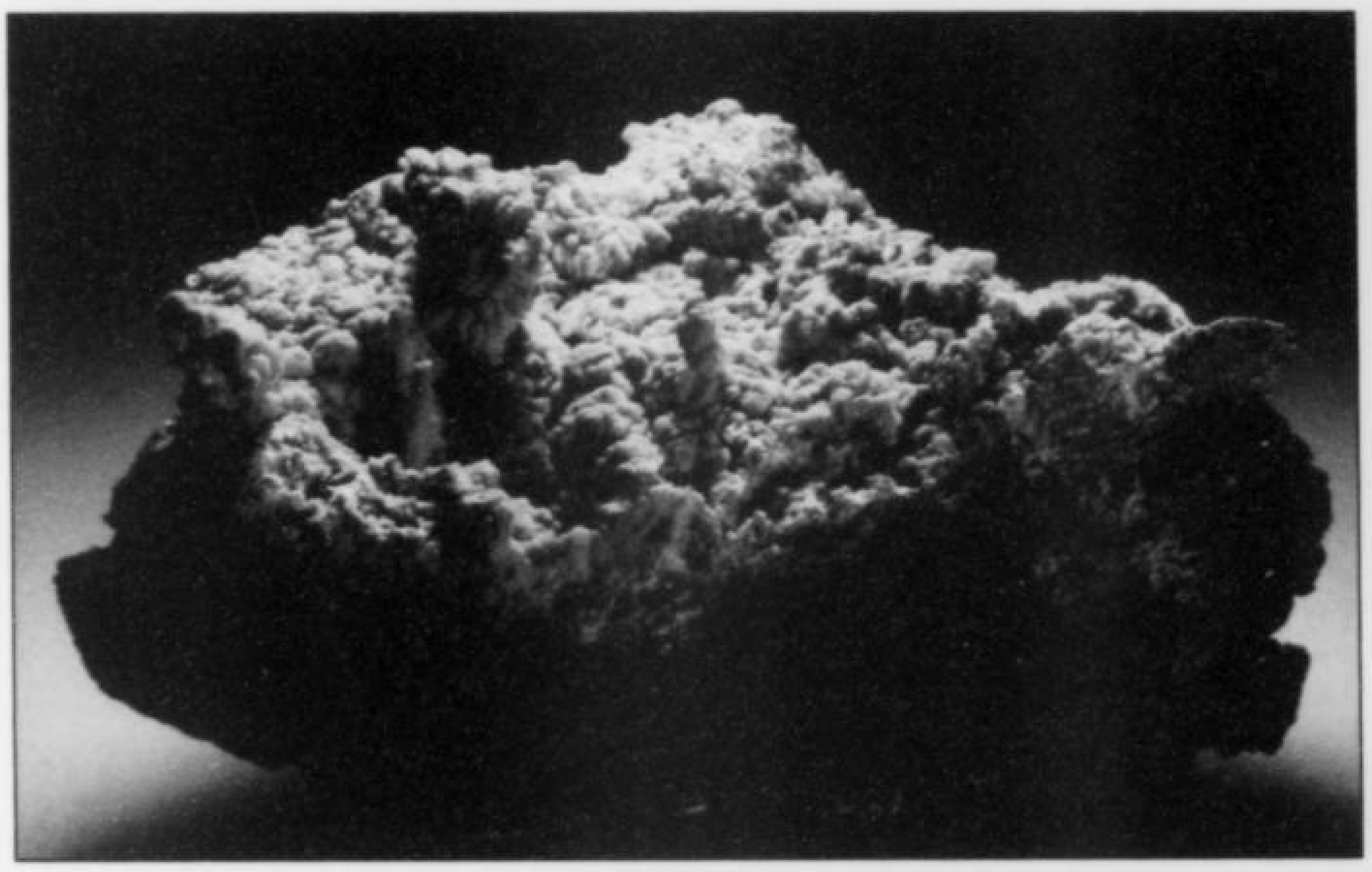
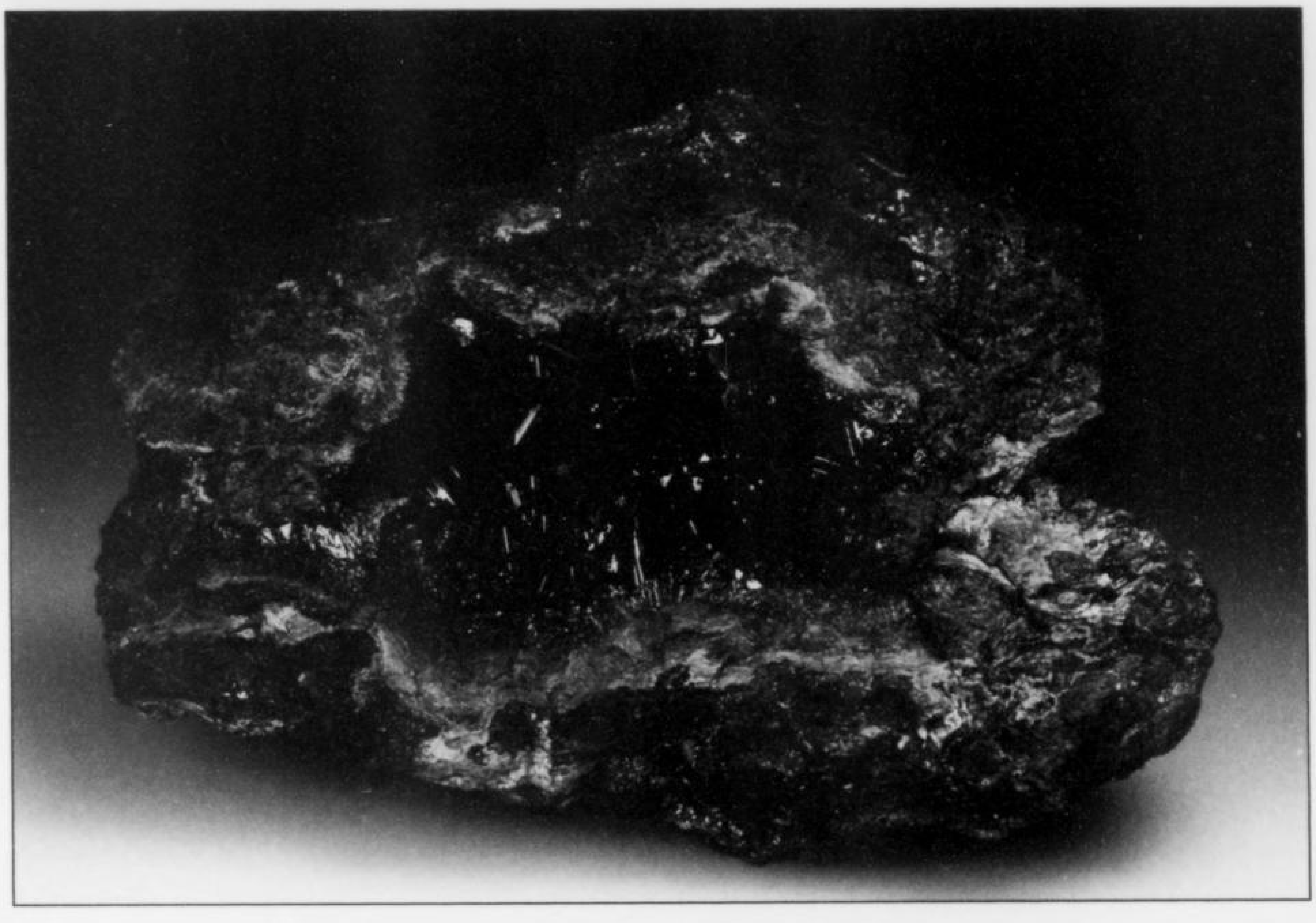


Figure 14. Chalcoalumite, 9.6 cm, from the Lavender pit, Bisbee, Arizona. Graeme collection; Wendell Wilson photo.

Figure 15. Claringbullite, 5 cm, from the Southwest mine, Bisbee, Arizona. Graeme collection; Wendell Wilson photo.



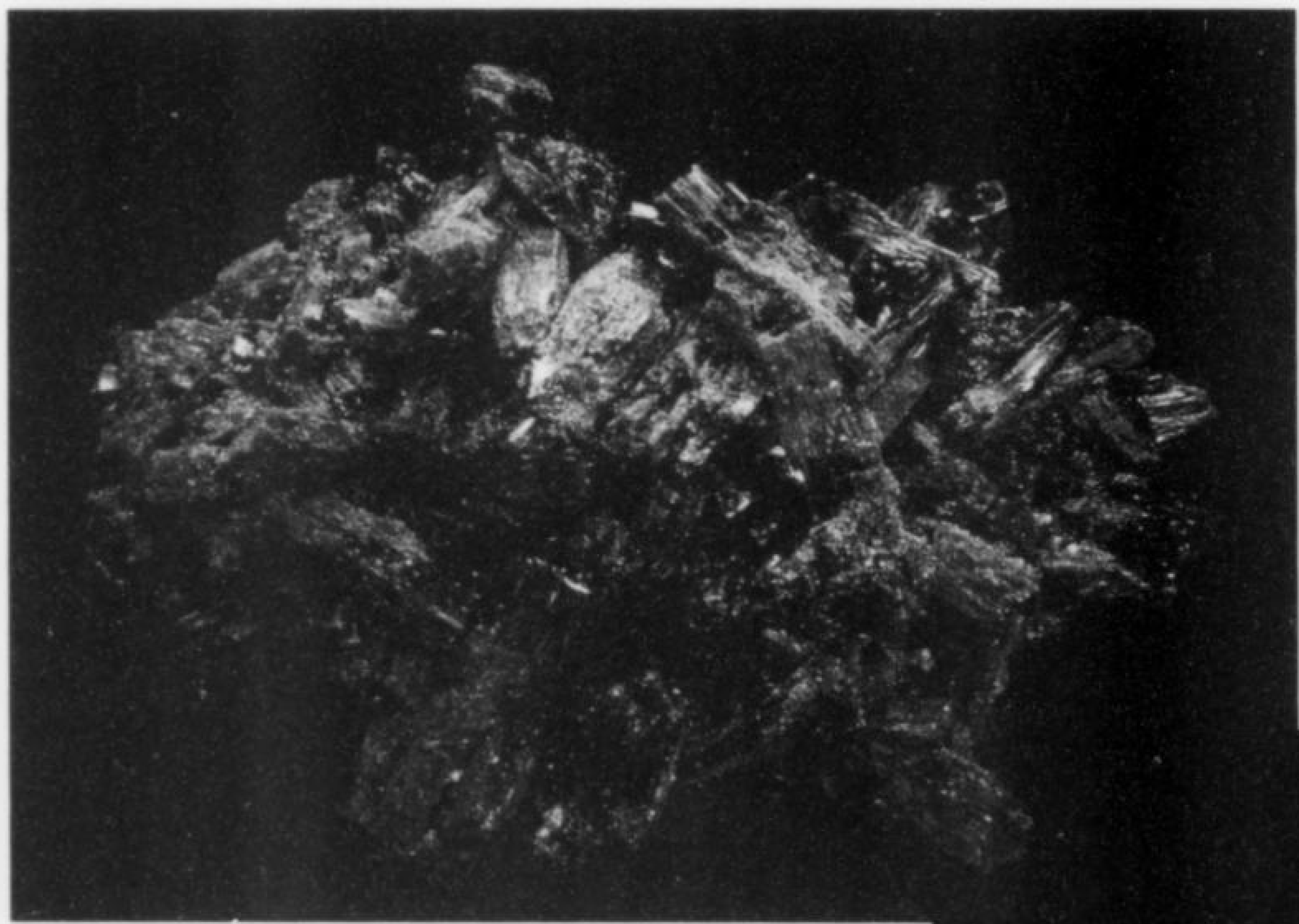


Figure 16. **Malachite, 6.5 cm, from the Uncle Sam mine, Bisbee, Arizona. Graeme collection; Jeff Scovil photo.**

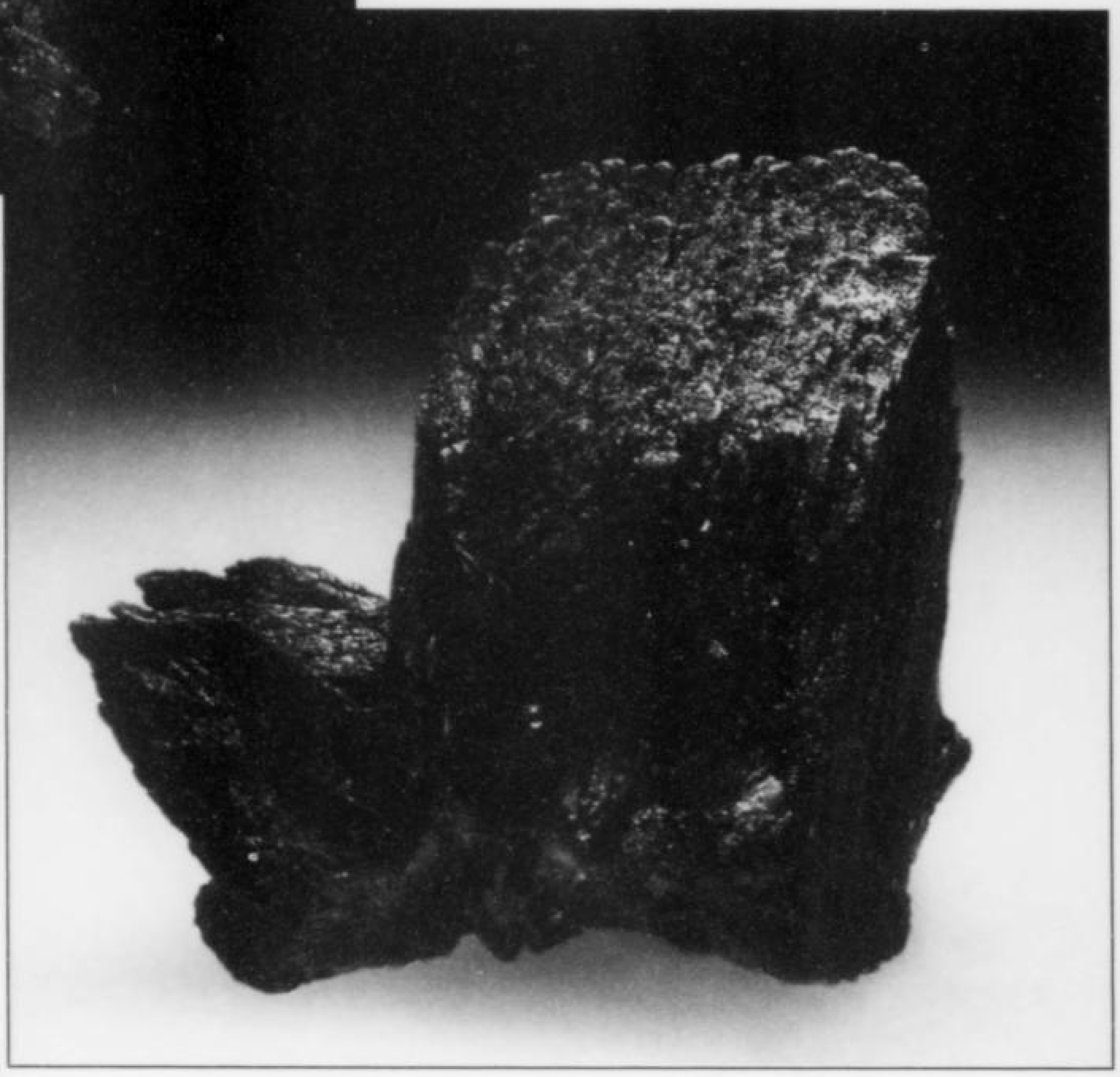


Figure 17. **Malachite (primary crystals), 4.5 cm, from the Campbell shaft, Bisbee, Arizona. Graeme collection; Wendell Wilson photo.**

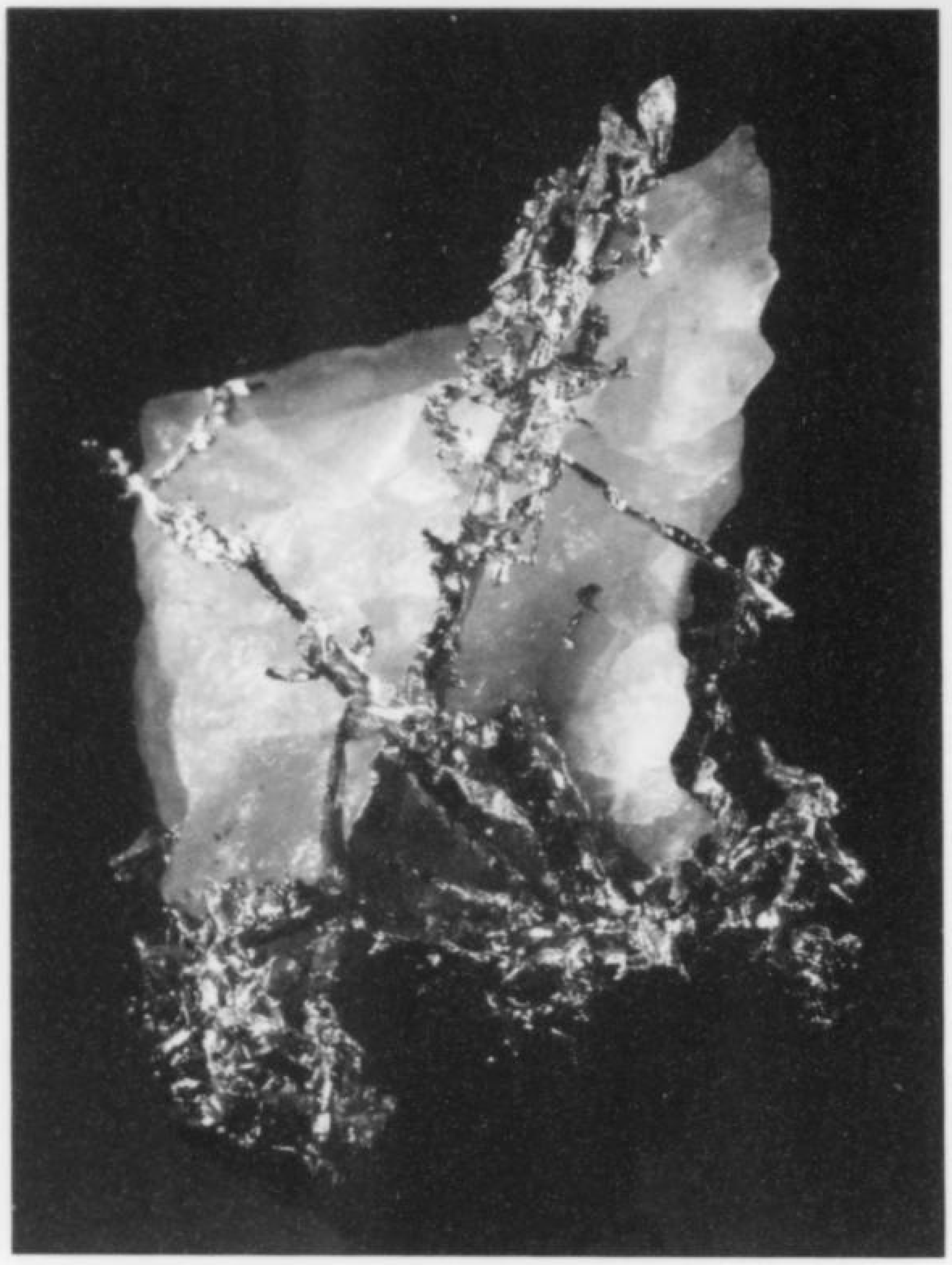


Figure 18. **Gold in quartz, 2.5 cm, from Bisbee, Arizona. Graeme collection; Wendell Wilson photo.**

groups of gleaming blades, each many centimeters on edge, making midnight thrusts in many directions. Malachite shows off as rich green, botryoidal pieces with a lustrous "finish" as if highly polished; as stalactiform shapes seemingly draped in green velvet; and, of course, as big clusters of wedge-terminated pseudocrystals after azurite. Less familiar-looking specimens represent the best extant crystallized Bisbee brochantite, atacamite, cerussite, hemimorphite, and many rare species, including some extremely rare ones which accompany cuprite, a species which I have saved for last in this listing because it is the star player in the account of the Graemes' greatest single collecting adventure at Bisbee.

Exploring the 5 level of the Southwest mine one day in August of 1986, Dick and his sons spotted a suspiciously altered-looking area on a mine wall, with, just behind it, a tiny vug of bright blue, acicular microcrystals which turned out later to be the very rare species connellite and claringbullite. From the area, marking a clay-filled fault zone, they were finally able to pry loose two boulders of massive cuprite the size of filing cabinets. What they found in the boulders has been briefly described by Wilson (1987), but hearing the Graemes tell about it is much more exciting than reading about it. Cracking open a malachite-atacamite nodule attached to one of the cuprite boulders, they uncapped a 10-cm vug lined with sharp, mirror-faced, deep red, totally gemmy, modified-cubic cuprite crystals to 5 cm on edge. The vug, intact, is presently a single great specimen in the display collection, as the cuprite crystals proved too tightly intergrown to extract separately; to peer

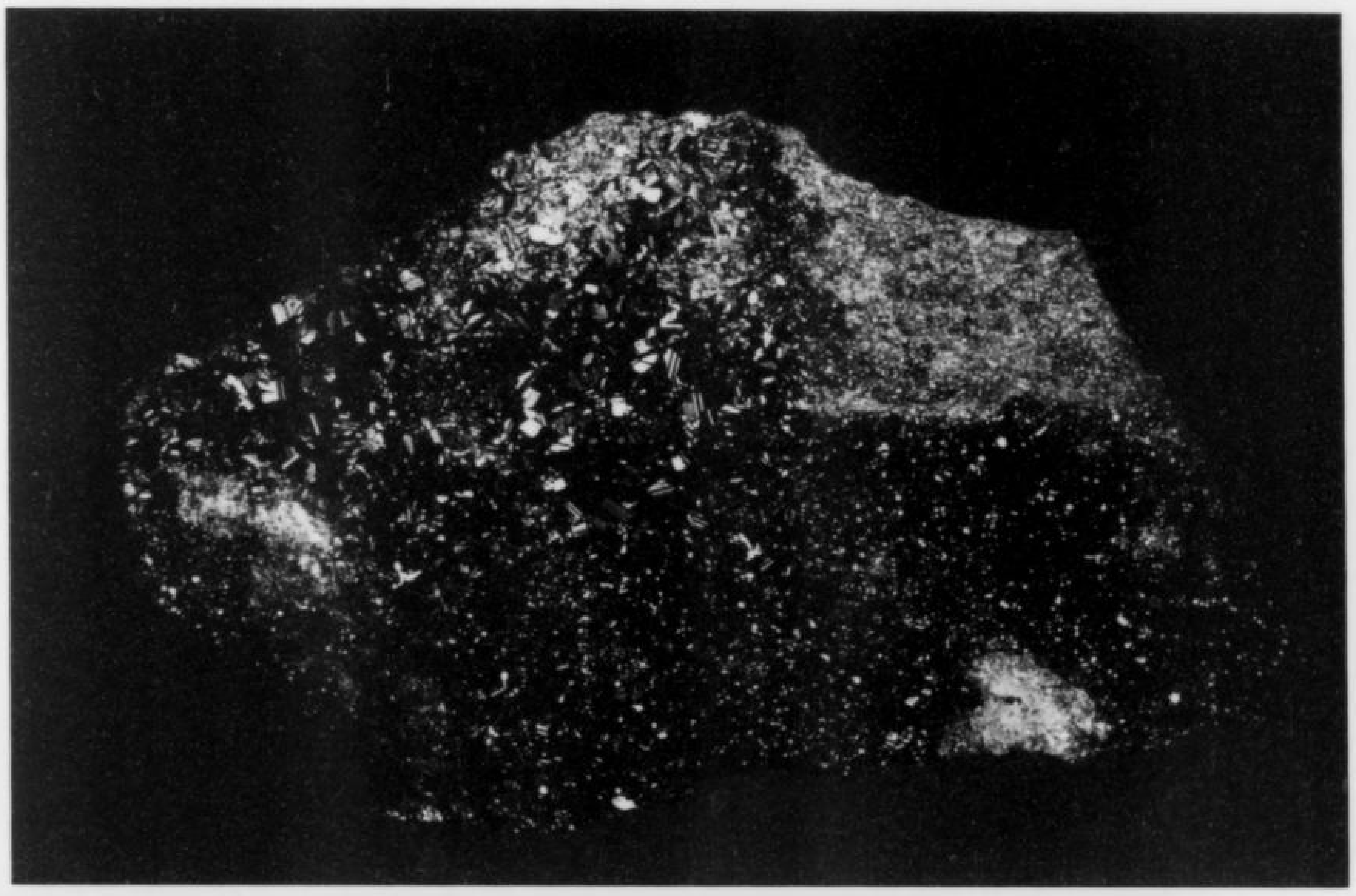


Figure 19. **Antlerite, 11.5 cm, from the Shattuck mine, Bisbee, Arizona. Graeme collection; Jeff Scovil photo.**

Figure 20. **Cerussite, 7.1 cm, from the Gardner mine, Bisbee, Arizona. Graeme collection; Jeff Scovil photo.**

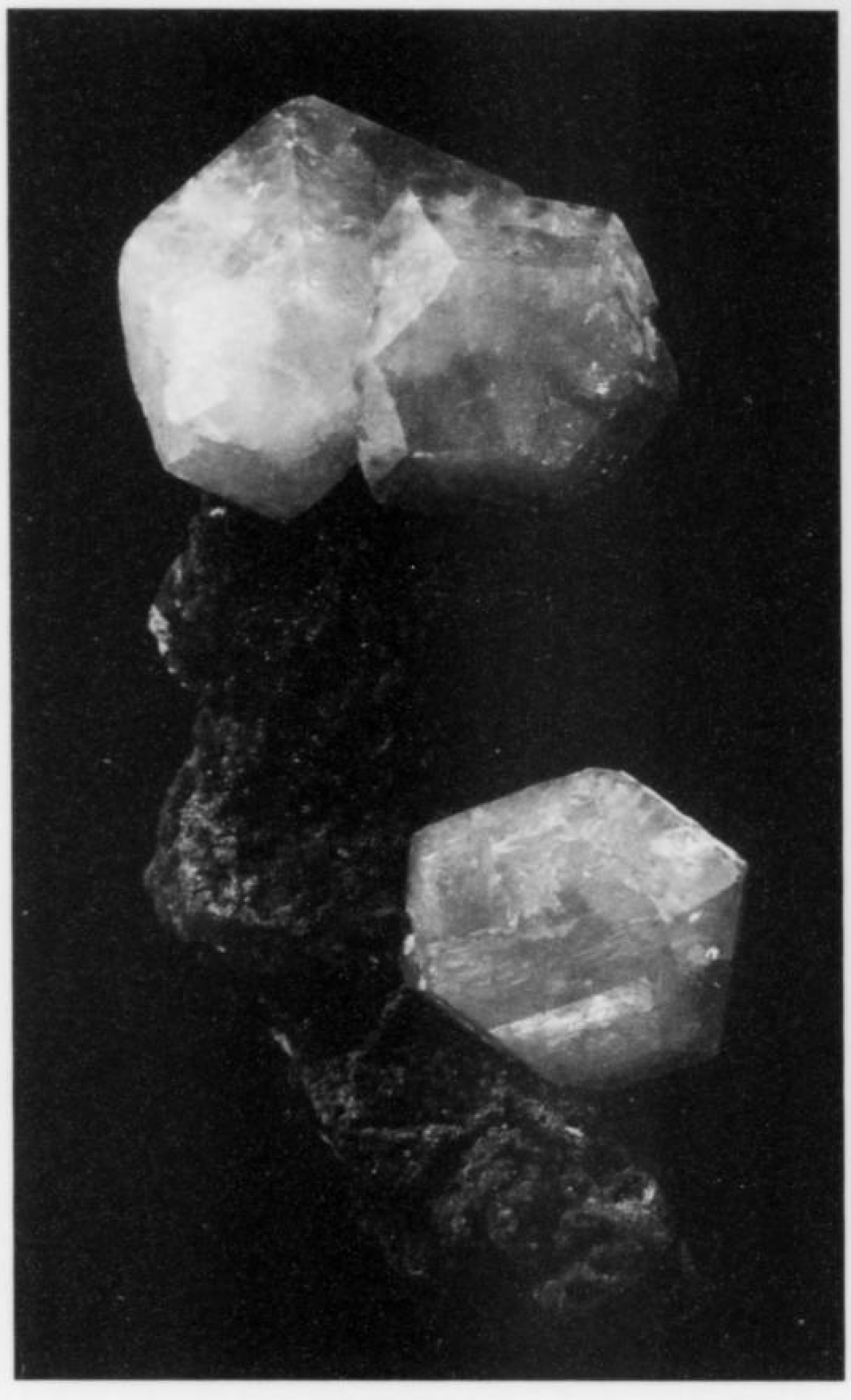


Figure 21. **Calcite, 3 cm, from the 2566 level, Campbell mine, Bisbee, Arizona. Graeme collection; Jeff Scovil photo.**

into this cavity is to see one's face partly reflected in what looks like a set of mirrors attached at angles—the faces of the huge cuprite crystals. A single amazing specimen which emerged from the find consists of a discrete, gemmy red cuprite crystal, 2.6 cm on edge, sitting up smartly on a green bed of antlerite microcrystals over massive cuprite: this incredible specimen was the talk of the 1987 Tucson show, and was published on the cover of vol. 18, no. 3 of the *Mineralogical Record* (and is also shown here).

Nor is that all to say about what the Graemes call their Labor Day find (since it took them from late August into early September 1986 to thoroughly clean out the mineralized zone). When the cuprite boulders were hammered upon, an overwhelming smell of chlorine arose, and waxy, colorless masses of nantokite (CuCl) the size of footballs fell out. Little pockets still full of chlorine brine gave up floater groups, to 2.5 cm, of vivid, 2-mm cuprite crystals. And finally there were specimens of superbly well crystallized atacamite, paratacamite, connellite, claringbullite, spangolite, and other very rare secondary chlorides—23 species in all (see Graeme, 1993).

Figure 22. **Calcite, 8.3 cm, from the Southwest mine, Bisbee, Arizona. Graeme collection; Jeff Scovil photo.**

CONCLUSION

Dick Graeme continues in every time-off interval he gets from work—for he doesn't think of "retiring"—to build his Bisbee collections. His sons, we may be sure, will also keep up the work, whatever else they may be doing, after Dick is gone. And Richard IV's son, Richard V, now 2 , is being benignly indoctrinated already , just as his father was, in the beauty (the science can come a bit later) of Bisbee minerals. However, even if there turns out to be no fifth generation of Graemes interested in carrying on with the accumulation and study of Bisbee specimens, several kinds of permanent record will have been firmly fashioned: the Bisbee collection itself, the two forthcoming books by the Graemes, and the mass of periodical publications, computerized annals, and other sorts of love-letters addressed by one family to one, very particular, mineralogically very extraordinary, place. Dick is self-conscious about preserving *Bisbee!* for posterity, talking unpretentiously but frequently of his pride in the work. And why not? Can't we all think of about ten other world-class localities that we wish were served so well?

BIBLIOGRAPY

GRAEME, R. W. (1981) Famous mineral localities: Bisbee, Arizona. *Mineralogical Record*, **12**, 258-319.

GRAEME, R. W. (1993) Bisbee revisited: an update on the mineralogy of this famous locality. *Mineralogical Record*, **24**, 421-436.

WILLIAMS, S.A. and MATTER, P. (1975) Graemite, a new Bisbee mineral. *Mineralogical Record*, **6**, 32-34.

WILSON, W.E. (1987) What's new in minerals? Tucson Show 1987. *Mineralogical Record*, **18**, 241-246.

Letters

Purpose of Museums

John White's editorial on "The Purpose of Museums" in the July-August issue, in which he objects to museums becoming more educationally designed instead of just showing the maximum number of specimens, is written from the "purist" perspective. In a perfect world, all natural history museums would have adequate staff, collections storage facilities, and exhibit space to display their specimens. Unfortunately, we don't live in such a world. With the exception of the National Museum of Natural History, I know of no natural history museum in the country that can afford to focus solely on pure scientific research and exhibits. While it is true that museums are the best place to see the finest minerals, fossils and other non-living specimens, the costs of paying for professional staff and facilities maintenance has become so high and revenue has fallen so low that transforming into an "educational institution" has become necessary for their very survival! Most museums compete with dozens if not hundreds of other institutions and attractions to draw in paying visitors, sponsorships, and financial grants of all types.

Having been involved in a museum that has become a science center, and now working in a state park that has a museum, I can speak with some 20 years of professional experience in this subject. Many natural history museums are in danger of becoming irrelevant to the general public because they lack the "pizzazz" of zoos, aquaria, and other experiential places that individuals and families have come to prefer. Museum boards of directors are finding that utility bills must be paid, aging facilities must be renovated, and staff must be paid with the income generated by visitor services, rentals and gift shop profits just as much as grants and governmental funds. Sadly, marketing is becoming more important than collections acquisitions if the museums are to continue operating.

The first museums were private collections of wealthy people. The institutional museums appeared some time later. Today's museums continue to evolve. What will tomorrow bring? Who knows? But we mustn't fear change. Museums *must* continue to serve as repositories for and of our society. I have no argument with John in that respect. On the other hand, holding dear to the old ways will not save museums that can't pay their bills. Museums must evolve and adapt in order to be able to survive and maintain their collections. They don't just acquire for today—they do so for future generations! Survival is the ultimate goal of every museum.

Alan Goldstein
Louisville, Kentucky

Sapo Mine Apatite

Concerning the reported Sapo mine "carbonate-fluorapatite" first imported to Italy by Riccardo Prato some months ago, the initial analyses were made by Francesco Demartin and Italo Campostrini at the Dipartimento di Chimica Strutturale e Stereochimica Inorganica of the University of Milan. I first heard that the crystals had been identified as "carbonate-apatite" (lacking fluorine) but I was not confident of the preliminary results. Nevertheless, that name and reports of the analyses began to circulate in the mineral specimen market and, inasmuch as "carbonate-apatite" is not a valid species name, some people (probably dealers on the web) decided to call it "carbonate-fluorapatite."

For some unknown reason, some people also started saying that the analyses were made by me and, at the Munich show in Germany last October, I informed various colleagues who were asking me for information, that the preliminary studies made by Demartin and Campostrini were far from being sufficient for an accurate determination of the mineral species.

After I returned from Germany, Demartin told me that he (and Campostrini) had first made an EDS spectrum of the mineral which showed a nearly total absence of F and a high content of C. They later made an X-ray powder diffraction analysis and the result was compatible with "carbonate-hydroxylapatite." I was still not convinced by these results, because finding carbonate-hydroxylapatite in such a geological environment would have very significant and unusual petrogenetic implications. I told them that I would want to make new WDS analyses myself for confirmation. They were not happy with this but they immediately renewed their own investigations, polishing samples for WDS analyses and infrared spectroscopy. The amazing result was Demartin's discovery that the crystal he had originally used for study had been contaminated by oil. In his opinion this oil, which had apparently been added for the purpose of enhancing the aesthetics of the specimen, was responsible for the erroneously high C value seen on the EDS spectrum.

Based on the additional analyses, the mineral therefore appears to be **hydroxylapatite**. Unfortunately it may be a long time before the labels for all of the many specimens recovered from this find have been corrected.

Federico Pezzotta
Natural History Museum, Milan

Francon Quarry

I am still swooning over the Francon Quarry article. It's like memories of an old flame!

Steven C. Chamberlain
Syracuse, New York

The Label Archive

This is great. Thanks so much for putting in the effort. I have just sent you about 40 labels to add to the Archive. I will keep the project in mind as I see odd "paper."

Dr. Robert B. Cook
Auburn University

Thank you for undertaking such a project. I have numerous dealer or collector labels with older specimens, and often know little if anything about the former owners. Something like this will be an invaluable reference for those of us who are fascinated by the history of their specimens. Your article inspired me to spend a good portion of the weekend scanning old labels and appending them to the corresponding mineral photos in my computer catalog.

Jesse Fisher
San Francisco, CA

I am enthralled by your article on labels in this month's *Mineralogical Record*! I also like to collect original labels but I have an insignificant number compared to your sources. I would like to keep the labels with the specimens, but would you settle for pictures?

Dave Harris

Yes, we would definitely like to receive scans or prints (in color, over 400 dpi) for any labels we don't have. You can check our complete inventory list on the Axis *portion of our website, and see what we still need. It doesn't specify address and style variations, but we update it regularly.*
WEW

Thanks for doing the project. I have done some work in museums and in documentary film, and really appreciate keeping information accessible for future users.

Ellen Bynum
LaConner, WA

I am a subscriber to *The Mineralogical Record* and I read recently your article about your Label Archive. I find your idea, to install such an archive on the Internet, very good, therefore I went immediately to see it. Your article also inspired me, to improve my own label once more: I am introducing the family crest. When the work is finished, I will send some examples to you.

Werner Wurster
Pfinztal, Germany

I've finally had time to explore the online version of the Label Archive. This is an absolutely terrific endeavor and very, very useful for collectors of specimens with provenance, as well as for historians of mineralogy. I am going to collect and send you all the extra labels I have with whatever information I may have, as well as additional information about entries you have that are incomplete.

Dr. Steven C. Chamberlain
Syracuse University

Specimen Mortality

Further to the letter in the July-August issue by Ben Grguric (concerning mineral specimen mortality): In 1961 I returned from Boron, California with four hand-size specimens of inderite. I soaked them in water to remove the soft clay from around the delicate 1-inch crystals, then placed them out by a Joshua tree to dry. Later, I noticed my dog at that tree. She was wagging her tail and seemed quite elated. As I approached, to quell my curiosity, I could hear crunch, crunch, crunch. She was eating my inderite! I couldn't get mad at something so funny, but I realized that if I ever ran out of dog food, I could give her a bowl of howlite.

Al Ordway
Hesperia, CA

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Top Shelf Minerals
Quality minerals for advanced collectors
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e-mail: greg@topshelfminerals.com

Trafford-Flynn Minerals
Affordable Worldwide Quality Minerals
www.trafford-flynn.com
e-mail: info@trafford-flynn.com

The Vug
A very extensive mineral link portal
www.the-vug.com
e-mail: steve@the-vug.com

The Webmineralshop
Specializing in Fine Italian Minerals
www.webmineralshop.com
e-mail:webminerals@libero.it

Gerd M. Wiedenbeck
Alpine Minerals, Fine Worldwide Specimens
www.alpine-minerals.de
e-mail: minerals@uc-tec.de

Wright's Rock Shop
Fine Worldwide Minerals
www.wrightsrockshop.com
e-mail: wrightsr@ipa.net

**List your internet site here! Contact the editor at minrec@earthlink.net*

THE MUSEUM DIRECTORY

New York State Museum
Curator (Geol.): Dr. William Kelly
Tel: 518-474-7559
Collections Mgr. (Geol.):
Michael Hawkins
Tel: 518-486-2011
Fax: 518-486-3696
3140 Cultural Education Ctr.
Albany, NY 12230-0001
Website: www.nysm.nysed.gov
Hours: 10–5 daily (closed Thanksgiving, Christmas, New Years)
Specialty: New York & worldwide minerals
Support Org.: NY State Acad. of Mineralogy (www.nysm.nysed.gov/nysam)

Colburn Earth Science Museum
Curator: Phillip M. Potter
Tel: (828) 254-7162
Fax: (828) 257-4505
Website: www.colburnmuseum.org
Pack Place Education,
Arts & Science Center
2 South Pack Square
Asheville, NC 28801
Hours: 10–5 Tues.–Sat.
1–5 Sun. Closed Mondays and holidays
Specialties: North Carolina and worldwide minerals and gems
Accessible to persons with disabilities

Montana Tech Mineral Museum
Curator: Dr. Richard Berg
Tel: 406-496-4172
Fax: 406-496-4451
E-mail:dberg@mtech.edu
Program Director: Ginette Abdo
Tel: 406-496-4414
E-mail:gabdo@mtech.edu
Website: www.mbmg.mtech.edu /museumm.htm
Montana Bureau of Mines & Geology
Montana Tech of UM,
1300 W. Park Street
Butte, Montana 59701
Hours: Mem/Day to Labor Day 9-6 daily; Rest of year M-F 9-4; Open Sat & Sun May, Sept & Oct 1-5 pm
Specialties: Butte and Montana minerals, worldwide classics

Western Museum of Mining & Industry
Curator: Terry A. Girouard
Tel: (719) 495-2182
email: wmmicurator@aol.com
Dir. of Educ.: Scott Wright
Tel: (719) 488-0880
Fax: (719) 488-9261
www.wmmi.org
1025 North Gate Road
Colorado Springs, CO 80921
Hours: 9–4 M-Sat.
Specialties: Colorado minerals & ores, Western mining memorabilia, 14,000-vol. research library

The Gillespie Museum of Minerals, Stetson University
Bruce Bradford
Tel: (904) 822-7331
E-mail: bbradfor@stetson.edu
Assistant Director: Holli M. Vanater
Tel: (904) 822-7330
E-mail: hvanater@stetson.edu
Fax: (904) 822-7328
234 E. Michigan Avenue
[mailing: 421 N. Woodland Blvd. Unit 8403]
DeLand, FL 32720-3757
Hours: 9-noon, 1–4 M-F; closed during univ. holidays, breaks, summer
Specialties: Worldwide comprehensive collection of rocks & minerals; Florida rocks, minerals & fossils; large historic fluorescent collection

Colorado School of Mines
Curator: Paul J. Bartos
Tel: (303) 273-3823
E-mail:pbartos@mines.edu
Website: www.mines.edu/academic/ geology/museum
Golden, Colorado 80401
Hours: 9–4 M–Sat., 1–4 Sun. (closed on school holidays & Sundays in the summer)
Specialties: Worldwide minerals; Colorado mining & minerals

A. E. Seaman Mineral Museum
Website: www.museum.mtu.edu
Curator & Professor of Mineralogy:
Dr. George W. Robinson
E-mail: robinson@mtu.edu
Tel: 906-487-2572; Fax: 906-487-3027
Electrical Energy Resources Center
Michigan Technological University
1400 Townsend Drive
Houghton, MI 49931-1295
Summer Hrs (July-Sept.): M–F: 9–4:30, S–S: 12–5
Winter Hrs (Oct–June): M–F: 9–4:30
*Closed Mondays: Nov–Mar.
Specialty: Michigan minerals, Lake Superior region & Midwest U.S. minerals

Houston Museum of Natural Science
Curator (mineralogy): Joel Bartsch
Tel: (713) 639-4673
Fax: (713) 523-4125
1 Herman Circle Drive
Houston, Texas 77030
Hours: 9–6 M–Sat., 12–6 Sun.
Specialty: Finest or near-finest known specimens

Natural History Museum of Los Angeles County
Fax: (213) 749-4107
Website: http://nhm.org/minsci
Curator (Mineral Sciences):
Dr. Anthony R. Kampf
Tel: (213) 763-3328
E-mail: akampf@nhm.org
Collections Manager:
Dorothy L. Ettensohn
Tel: (213) 763-3327
E-mail: dettenso@nhm.org
900 Exposition Blvd.
Los Angeles, CA 90007
Hours: 9:30–5:00 Daily
Specialties: Calif. & worldwide minerals, gold, gem crystals, colored gemstones, micromounts
Support organization:
The Gem and Mineral Council

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Send vital information, as shown, to the editor. There is a modest annual fee (lower than our regular advertising rates).

Museums listed alphabetically by city

THE MUSEUM DIRECTORY

W. M. Keck Earth Science & Engineering Museum

Administrator: Rachel A. Dolbier
Tel: 775-784-4528, Fax: 775-784-1766
E-mail: rdolbier@unr.edu
Website: http://mines.unr/edu/museum
Mackay School of Earth Science & Engineering
University of Nevada, **Reno** 89557
Hours: 9–4 Mon.–Fri. (closed university holidays) and by appointment
Specialty: Comstock ores, worldwide minerals, mining artifacts, Mackay silver

Arizona Mining & Mineral Museum

Department Director: Doug Sawyer
Curator: Sue Celestian
Tel: (602) 255-3795
1502 W. Washington Avenue
Phoenix, AZ 85007
Hours: 8–5 M–F, 11–4 Sat., closed Sun. & holidays
Specialty: Arizona minerals

Matilda and Karl Pfeiffer Foundation Museum

Executive Director: Teresa Taylor
Tel: (870) 598-3228
E-mail: execdir@ pfeifferfoundation.org
P.O. Box 66
1071 Heritage Park Drive
Piggott, AR 72454
Hours: 9–4 Tues.–Fri., 11–4 Sat. (Daylight Savings Time)
Specialties: Fine collection of geodes from Keokuk, Iowa, area; worldwide collection of minerals

Carnegie Museum of Natural History

Collection Manager: Marc L. Wilson
Tel: (412) 622-3391
4400 Forbes Avenue
Pittsburgh, PA 15213
Hours: 10–5 Tues.–Sat., 10–9 F, 1–5 Sun., closed Mon. & holidays
Specialty: Worldwide minerals & gems

New Mexico Bureau of Mines & Mineral Resources—Mineral Museum

Director: Dr. Virgil W. Lueth
Tel: (505) 835-5140
E-mail: vwlueth@nmt.edu
Fax: (505) 835-6333
Associate Curator: Robert Eveleth
Tel: (505) 835-5325
E-mail: beveleth@gis.nmt.edu
New Mexico Tech,
801 Leroy Place
Socorro, NM 87801
Hours: 8–5 M–F, 10–3 Sat., Sun
Specialties: New Mexico minerals, mining artifacts, worldwide minerals

Arizona-Sonora Desert Museum

Fax: (520) 883-2500
Website: http://www.desertmuseum.org
Curator, Mineralogy: Anna M. Domitrovic
Tel: (520) 883-3033
E-mail: adomitrovic@desertmuseum.org
2021 N. Kinney Road
Tucson, AZ 85743-8918
Hours: 8:30-5 Daily (Oct.-Feb.) 7:30-5 Daily (Mar.-Sept.)
Specialty: Arizona minerals

Pacific Museum of the Earth

Curator: Kirsten Parker
Tel: (604) 822-6992
E-mail: kparker@ubc.ca
Dept. of Earth and Ocean Sciences
Univ. of British Columbia
6339 Stores Rd.
Vancouver, BC, Canada V6T 1Z4
Hours: 9–4, M–F
Specialties: BC–Yukon–Pacific NW, Worldwide Gold & Silver

U.S. National Museum of Natural History (Smithsonian Institution)

Curator: Dr. Jeffrey E. Post
E-mail: minerals@nmnh.si.edu
Collection Managers: Paul Pohwat and Russell Feather (Dept. of Mineral Sciences)
Washington, DC 20560-0119
Hours: 10 am–5:30 pm daily
Specialties: Worldwide minerals, gems, research specimens

William Weinman Mineral Museum

Website: www.weinmanmuseum.org
Director and Curator: Jose Santamaria
Tel: (770) 386-0576 x 401
Fax: (770) 386-0600
51 Mineral Museum Dr.
White, GA 30184
Mailing Address:
P.O. Box 3663
White, GA 30184
Hours: 10–4:30 Tues.–Sat., 2–4:30 Sun.
Specialty: Georgia & worldwide minerals & fossils

University of Delaware Mineralogical Museum

Penny Hall,
Newark, DE 19716
University of Delaware
For directions, hours, contacts and a virtual tour see
www.museums.udel.edu/mineral
Specialty: Worldwide Classic & New Minerals

Museo Civico di Storia Naturale

Curator: Dr. Federico Pezzotta
Tel: +39 02 8846 3326
Fax: +39 02 8846 3281
E-Mail: fpezzotta@yahoo.com
Associate Curator: Alessandro Guastoni
Department of Mineralogy and Petrography
Corso Venezia, 55
I-20121 **Milano,** Italy
Hours: 9 am–6 pm daily
Specialties: Italian minerals, pegmatite minerals

Gargoti Mineral Museum

Director: K. C. Pandey
Tel: ++91 2551 230528
Fax: ++91 2551 230866
D-59 MIDC, Malegaon, **Sinnar**, Nashik 422 103 India
Specialty: Minerals of India

Mineralogical Record

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minrec@aol.com

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7558 PN Hengelo OV.
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N-2740 Roa
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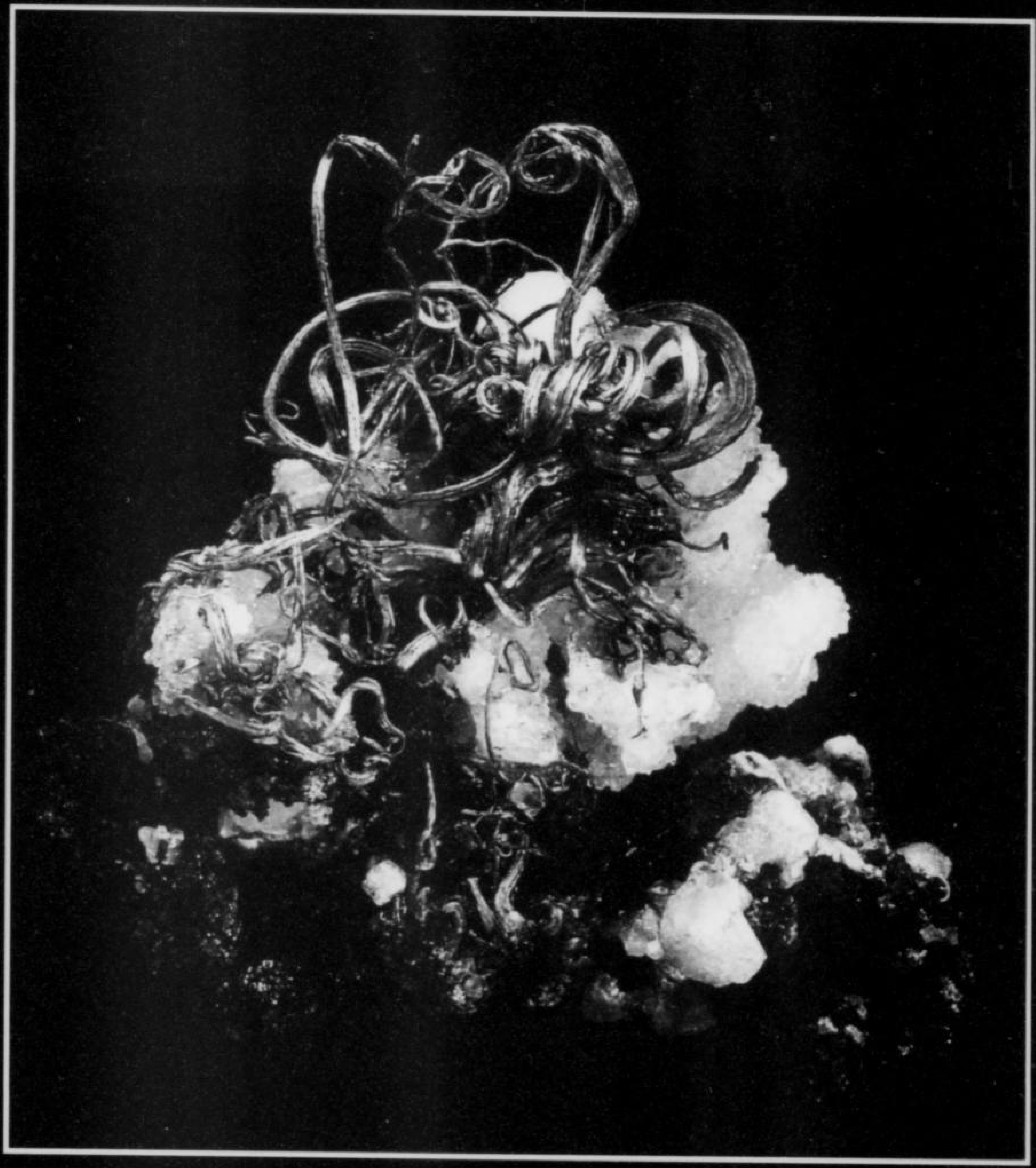

SILVER on Quartz, Bulldog mine, Creede, Mineral Co., Colorado. Photo by Jeff Scovil